NASA CR71502

VOYAGER SPACECRAFT SYSTEM

FINAL TECHNICAL REPORT

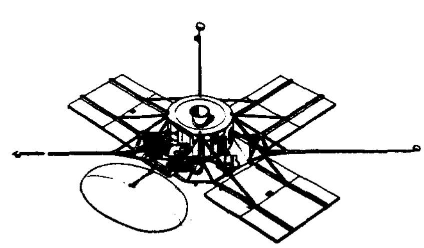
MANAGEMENT PHILOSOPHY AND PROGRAM HIGHLIGHTS

prepared for

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

UNDER
CONTRACT NO. 951111 NAS-7-100
JULY 1965

THE BOEING COMPANY • AERO-SPACE DIVISION • SEATTLE, WASHINGTON



THE BOEING COMPANY

SEATTLE, WASHINGTON 98124

LYSLE A. WOOD
VICE PRESIDENT-GENERAL MANAGER
AERO-SPACE DIVISION

July 29, 1965

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California

Gentlemen:

This technical report culminates nearly three years of Mariner/Voyager studies at Boeing. During this time, we have gained an appreciation of the magnitude of the task, and feel confident that the experience, resources and dedication of The Boeing Voyager Team can adequately meet the challenge.

The Voyager management task is accentuated by three prime requirements: An inflexible schedule of launch opportunities; the need for an information-retrieval system capable of reliable high-traffic transmission over interplanetary distances; and a spacecraft design flexible enough to accommodate a number of different mission requirements. We believe the technical approach presented here satisfies these design requirements, and that management techniques developed by Boeing for space programs will assure delivery of operable systems at each critical launch date.

Mr. E. G. Czarnecki has been assigned program management responsibility. His group will be ably assisted by Electro-Optical Systems in the area of spacecraft power, Philco Western Development Laboratories will be responsible for telecommunications, and the Autonetics Division, North American Aviation will provide the auto-pilot and attitude reference system. This team has already demonstrated an excellent working relationship during the execution of the Phase IA contract, and will have my full confidence and support during subsequent phases.

This program will report directly to George H. Stoner, Vice President and Assistant Division Manager for Launch and Space Systems. Mr. Stoner has the authority to assign the resources necessary to meet the objectives as specified by JPL.

The Voyager Spacecraft System represents to us more than a business opportunity or a new product objective. We view it as a chance to extend scientific knowledge of the universe while simultaneously contributing to national prestige and we naturally look forward to the opportunity of sharing in this adventure.

Lysle A. Wood

Lysle A. Wood

THE BOEING COMPANY

SEATTLE 24, WASHINGTON

July 28, 1965

WILLIAM M. ALLEN
PRESIDENT

Dear Lysle:

I have received expressions of personal interest and support from Mr. J. L. Atwood, President of North American Aviation, Mr. J. C. Wilson, President of Xerox Corporation, and Mr. R. O. Fickes, President of Philco Corporation on the Voyager Spacecraft System effort. I wish to compliment you on the selection of these companies as your Voyager team members. Each will strengthen The Boeing Company capability to accomplish JPL's Voyager objectives.

I desire to assure you and George Stoner that the resources of the company required to meet our Voyager obligations will be available to you. As you know, I continually strive to improve the structure of the company to meet tomorrow's challenges, and to ensure at this time that proper identification and emphasis is being given to our space endeavors, I am establishing an Aero-Space Group under your corporate direction to focus our capabilities in this realm. In the near future the new Space Division will be formed within your Group under the direction of George H. Stoner.

William M. Allen

William M. Allen

Mr. Lysle A. Wood
Vice President - General Manager
Aero-Space Division

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William M. Allen
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Mr. Lysle A. Wood
Vice President - General Manager
Aero-Space Division

OF

NORTH AMERICAN AVIATION, INC.

GENERAL OFFICES • 1700 EAST IMPERIAL HIGHWAY • EL SEGUNDO, CALIFORNIA

OFFICE OF THE PRESIDENT

July 23, 1965

Mr. William M. Allen
President
The Boeing Company
Seattle, Washington

Dear Mr. Allen:

I wish to express my personal interest and support of our Autonetics Division in participating in Boeing's Voyager program. Our long and successful background of working together as team members on the Minuteman program should be extremely valuable and will be used to the maximum extent consistent with your requirements in the Voyager program.

It is North American Aviation's intention to insure the successful execution of its part in this important project.

Sincerely yours,

J. L. Atwood

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President

NORTH AMERICAN AVIATION, INC.
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J. L. Atwood

J. L. Atwood
President

PHILCO CORPORATION

A SUBSIDIARY OF Ford Motor Company

PHILADELPHIA 34
PENNSYLVANIA

ICE OF THE PRESIDENT

July 23, 1965

Boeing Company
Corporate Headquarter Offices
P. O. Box 3707
Seattle, Washington 98124

Attention: Mr. William W. Allen
President

Dear Mr. Allen:

Philco appreciates the opportunity to supply the Boeing Company with the telecommunications sub-system for the Voyager Spacecraft Program.

I have directed an increasing share of Philco Corporation's resources to support of major programs for the National Space effort. Philco management has concentrated on technical and cost performance on those programs entrusted to us. Recent examples of this effort include the implementation of the Mission Control Center at Houston which controlled the Gemini GT-4 flight as well as other systems and spaceborne equipment in support of the Mariner Program.

The Voyager program is of particular interest to Philco and it is our desire to support the Boeing Company efforts on this program. I wish to assure you that the total resources of the Philco Corporation will be mobilized for this program in the same manner in which our many technical capabilities were organized for the successful implementation of the Mission Control Center at Houston.

I believe that the impressive management and technical resources of the Boeing Company augmented by your selected sub-contractors will provide the Jet Propulsion Laboratories with the industrial resource required to ensure the success of this most challenging project.

Sincerely,

R. O. Fickes

Robert O. Fickes

PHILCO CORPORATION

A SUBSIDIARY OF Ford Motor Company

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Sincerely,

R O Fickes

Robert O. Fickes

XEROX
CORPORATION

OFFICE OF THE PRESIDENT

July 26, 1965

Dear Mr. Allen:

The tremendous successes of Ranger and Mariner IV during this past year have thrilled me. Xerox management is proud of the contribution which Electro-Optical Systems, Inc., our subsidiary, has made to these successes. This association with JPL and the deep-space program has been very gratifying to us.

We are pleased and proud to be part of the Boeing-Voyager team. We have great confidence that our team will provide the high quality and responsive support which JPL desires in carrying out the unmanned exploration of Mars with Voyager.

Our resolve to help create the strongest possible team for Voyager has been backed up by very substantial corporate financial commitments and expenditures. These include the decision to invest more than $5.74 million in expanding the EOS Space Sciences and Engineering Center, which will be completed this year, and the specific commitment and expenditure of more than $1 million of corporate funds, in addition to contract, overhead, and other funds to support our total Voyager effort. A Voyager Program Office has been established, with the program manager reporting directly to the EOS general manager, in order to assure maximum effectiveness in bringing EOS' total resources to bear on Voyager requirements.

We believe that nothing but the best will do for success in meeting the Voyager challenge. We have given the program our best and fullest support in the present competition, and look forward to continuing with further commitments and support to Voyager as the primary program at EOS.

Sincerely,

JCWilson

President

JCWilson
dap

Mr. William M. Allen, President
Boeing Corporation
P. O. Box 3707
Seattle, Washington 98124

4

CONTENTS

Full Scale Voyager Spacecraft Mock-Up

Left to Right

- William M. Allen
- Edwin G. Czarnecki
- Lysle A. Wood
- George H. Stoner

INTRODUCTION

In fulfillment of Jet Propulsion Laboratory (JPL) Contract 951111, The Boeing Company submits the Voyager Spacecraft final technical report, which consists of the following five documents:

Volume		Boeing Document No.
A	"Preferred Design for Flight Spacecraft and Hardware Subsystems" (Three Parts)	D2-82709-1
B	"Alternate Designs Considered for Flight Spacecraft and Hardware Subsystems"	D2-82709-2
C	"Design for Operational Support Equipment	D2-82709-3
D	"Design for 1969 Test Spacecraft"	D2-82709-4
E	"Design for Operational Support Equipment — 1969 Test Flight"	D2-82709-5

Presented here is a summary of the above five documents, providing an overview of the scope and depth of Boeing's understanding of the Voyager management task, and highlights of the technical management effort accomplished during Phase IA in preparation for this task.

The Boeing Company has a long history of assistance to the government as a team member in major system programs of national scope and importance. During this association, Boeing and the government have become increasingly aware of the importance of utilizing the most advanced technological, scientific, and industrial capability to evolve new systems for meeting national objectives. Experience on major systems has helped develop managerial concepts and capabilities, keeping pace with technological growth, that ensure realization of system objectives in a timely and effective manner. Traditional involvement during the formative period of major programs and with new technology applications, coupled with a management and industrial capability, have enabled Boeing to participate in many complex systems from their identification as a national requirement through implementation.

Specifically, Boeing's Aero-Space Division assisted the government as a major associate contractor on such programs as the Minuteman weapon system for SAC, and the Bomarc air defense system for ADC. This division also developed a technological and management capability for space-oriented systems during its involvement in the manned Dyna-Soar program, and in the launch and space field has been conducting the Saturn V/S-IC and Lunar Orbiter programs for the National Aeronautics and Space Administration. The long experience of Boeing with major systems, combined with a direct involvement in space programs over the past 8.5 years, has enabled the company to grasp the long-range significance of the operating medium of space as a major contribution to our national scientific and political posture.

Technological and product research has been sponsored at Boeing in increasing tempo over the last 5 years to understand and take advantage of the new dimensions of communication spectrum, mission time, trajectory and orbit flexibility, unique vantage point, and freedom from atmosphere involved with extended operations in space. A major effort to keep pace with pertinent developments such as reliability principles and sterilization techniques within the space-related sciences and component industries has accompanied intensive inhouse efforts on pertinent disciplines such as structures, microminiaturization, propulsion, reaction control, temperature control, sterilization, and data handling. The synthesis of all these into realistic space systems has been iterated with an increasing conviction of their practical application to the systematic exploration of the solar system.

This Boeing conviction concerning space flight and exploration has been backed by assigning to Mr. George H. Stoner, vice-president, and assistant division manager, Aero-Space Division, the responsibility for all space and launch activities of the company. His responsibilities include mobilization of the company's resources of skilled manpower, management capability, and applicable facilities to assist the government in the realization of the potential of space. In addition, the company has implemented the new Boeing Space Center facility in Kent, Washington (a suburb of Seattle), for which approximately 16 million dollars of company funds have already been expended for a space environmental simulator, space-flight simulator, microelectronics laboratory, and a space materials and processes laboratory. The planned development of this facility involves major investments during the next 10 years for additional fabrication, final assembly, laboratory, office, and administrative support capabilities. Site preparation and A and E work for the next phase of expansion are virtually complete. In Oregon, the company has activated the 100,000-acre Boardman test site on the Columbia River for space propulsion development activities, and is stepping up the use of the hazardous test site at Tulalip, Washington, for development of space-oriented components.

It is within this frame of reference that The Boeing Company has mobilized a most capable team of management, technical, and associated industry skills under Mr. Edwin G. Czarnecki, Voyager program manager, to undertake preliminary definition and eventual implementation of a major portion of the Voyager program.

MANAGEMENT PHILOSOPHY

ORGANIZATION

Within The Boeing Company, the Aero-Space Divison has been assigned the task of preparing for the design and development of Voyager. This division is one of the five operating divisions of the company reporting to Mr. William M. Allen, president, as shown in Figure 1.

Mr. Lysle A. Wood, vice-president and general manager, and Mr. Robert H. Jewett, vice-president and assistant general manager, manage the operations of the Aero-Space Division. The launch and space-systems activities are under the direction of Mr. George H. Stoner, vice-president and assistant division manager. Mr. Stoner reports directly to the general manager's office. Responsibility for the Voyager program is assigned to Mr. Edwin G. Czarnecki, program manager. Mr. Czarnecki reports directly to Mr. Stoner as shown in Figure 1, and has the authority to carryout Boeing's obligations for the Voyager program. To ensure strong and effective management of the Voyager program, Mr. Czarnecki will be assisted by the select management team shown in Figure 2. This team will be oriented to: (1) timely and effective communications and actions between Boeing, JPL, NASA agencies, and the associate contractors; and (2) a cost-effective approach to producing the spacecraft, integrating the payload, and supporting the conduct and evaluation of mission operations.

The Voyager management approach is based on: (1) the premise that all committed work must be planned, integrated, scheduled, budgeted, and accomplished to plan; and (2) the concept that this can be most effectively accomplished by a strong program-oriented team working within a space-oriented divisional organization. Boeing provides this strength through a clearly identified team in which individuals are dedicated singularly to the Voyager program and receive the full support of corporate top management.

The present organization of the company has been developed over the years to satisfy the requirements of the government, to meet the challenge of the technological revolution that has taken place in past years, and to make most effective use of Boeing's resources — manpower, facilities, and funds.

As a result of continuing studies involving organizational relationships within the company, the president, Mr. William M. Allen, has authorized moves to strengthen the elements of Boeing involved in today's space business interests and tomorrow's expanding potentials. Accordingly, the corporate environment shown in Figure 3 is that within which the Voyager program will be accomplished. As shown, the president and his staff, augmented by the group vice-presidents will constitute the Corporate Headquarters. Mr. Lysle Wood, group vice-president of the Aero-Space Group, assisted by Mr. Robert H. Jewett, will be the president's designates to manage and provide corporate support for the operating divisions of the Aero-Space Group. Under this arrangement, each

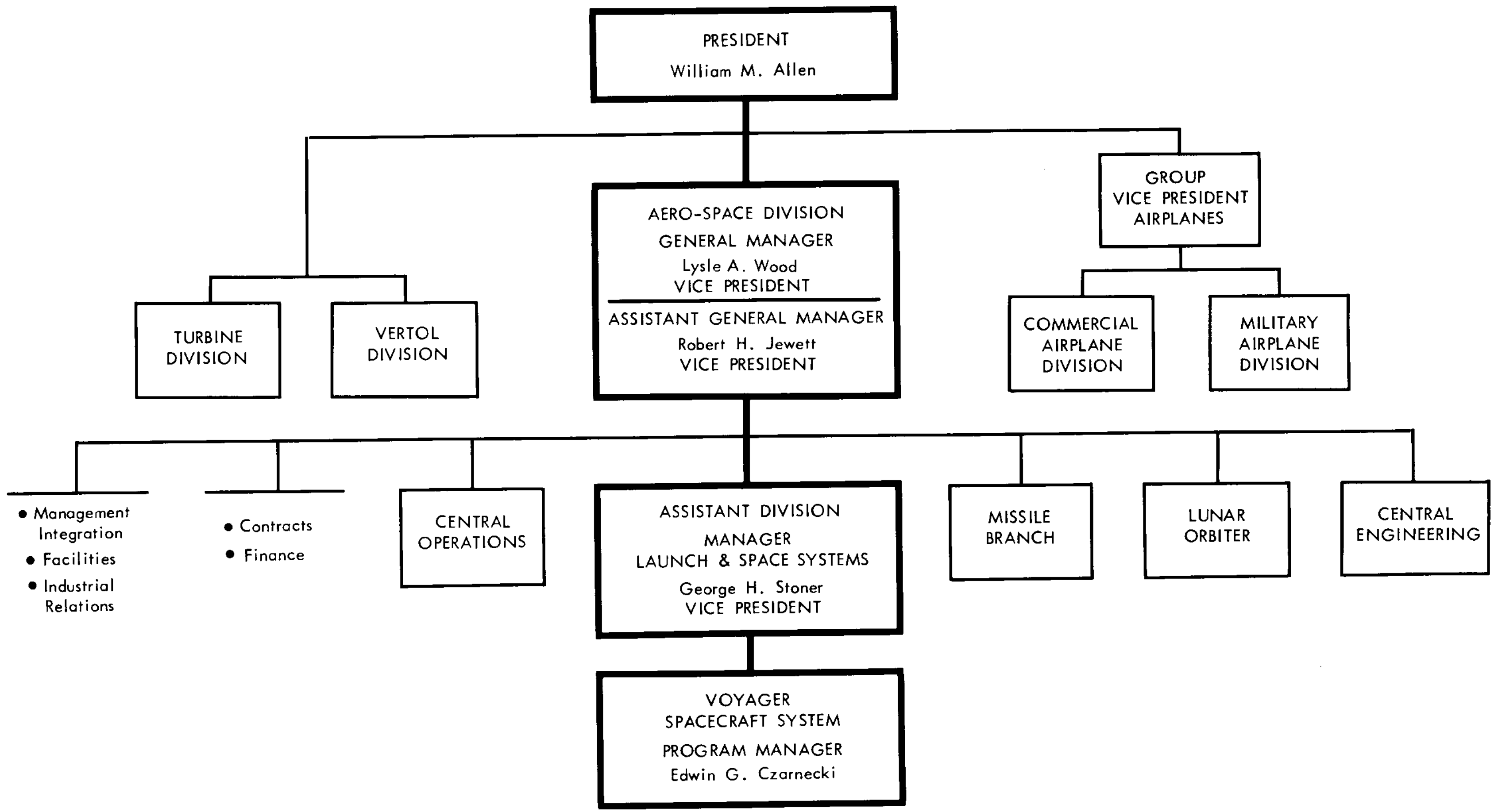

Figure 1: The Boeing Company — Organization

TECHNICAL REVIEW BOARD

NAME	TITLE OR POSITION	AFFILIATION
G. L. HOLLINGSWORTH	DIRECTOR	BOEING SCIENTIFIC RESEARCH LAB.
G. H. STONER	VICE-PRESIDENT	AERO-SPACE DIVISION
DR. F. PROSCHAN	VISITING PROFESSOR AT UNIVERSITY OF CALIFORNIA (BERKLEY)	BOEING SCIENTIFIC RESEARCH LAB.
S. SHAPIRO	DIR. OF PRODUCT DEVELOPMENT DESIGN	AERO-SPACE DIVISION
DR. L. DWYER	SYSTEMS ANALYSIS	AERO-SPACE DIVISION
DR. W. HANE	CHIEF SCIENTIST	AERO-SPACE DIVISION
DR. H. L. RICHTER	CORPORATE AREA TECHNICAL SPECIALIST	ELECTRO-OPTICAL SYSTEMS
DR. OTTO SCHWEDE	DIRECTOR TECHNICAL STAFF	PHILCO WDL
E. G. CZARNECKI	PROGRAM MANAGER	AERO-SPACE DIVISION

SYSTEMS TEST AND LAUNCH OPERATIONS MANAGER

K. K. MC DANIEL

- DEVELOP AND IMPLEMENT INTEGRATED TEST PLAN, SPACECRAFT ASSEMBLY & TEST PLAN AND LAUNCH OPERATIONS PLAN
- DEVELOPMENT REQUIREMENTS AND PLANS FOR MENTATION OF THE MOS
- IDENTIFICATION REQUIREMENTS FOR DSN SFO DEPENDENT EQUIPMENT AND PROGRAMS

FLIGHT SPACECRAFT COGNIZANT ENGINEERS

- DIRECT SPACECRAFT SYSTEM TESTS
- DIRECT SPACECRAFT FINAL ASSEMBLY TESTS & ACCEPTANCE TESTS
- DIRECT PRELAUNCH OPERATIONS AND CHECKOUT
- DIRECT SPACECRAFT LAUNCH OPS.

SYSTEMS TESTING

- PREPARE ASSEMBLY & CHECK OUT PLAN
- PREPARE INTEGRATED DATA MANAGEMENT PLAN
- ACTIVATE SYSTEM TESTING FACILITIES
- CONDUCT SYSTEM TESTING OF FLIGHT SPACECRAFT

TEST BOARD

- DEVELOP AN INTEGRATED TEST PLAN
- MONITOR INTEGRATED TEST PLAN
- CERTIFY TEST COMPLETION
- VALIDATE TEST DATA

LAUNCH OPERATIO

- PREPARE SPACECRAF PLAN
- ACTIVATE LAUNCH
- COORDINATE PRELA JPL/AFETR
- CONDUCT SPACECR

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FACILITIES

R. K. MILLS

- IDENTIFY INDUSTRIAL AND OPERATIONAL FACILITY REQUIREMENTS
- DEVELOP FACILITY PLANS INCLUDING FUNDING AND SCHEDULES
- COORDINATE FACILITY PLANS WITH JPL
- IMPLEMENT APPROVED PLANS AND CONTROL FUNDS
- CONTROL AND MAINTAIN PROGRAM FACILITY RESOURCES

OPERATIONS

L. B. BARLOW

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LAUNCH OPERATIONS

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MISSION OPERATIONS

- SUPPORT SPAT AND FPAT AT JPL
- CONDUCT MISSION OPERATIONS TRAINING
- IMPLEMENT MISSION-DEPENDENT OSE
- SUPPORT MOS ACTIVITIES

FABRICATION AND ASSEMBLY MANAGER

- FABRICATE MOCKUPS AND TEST MODELS
- DIRECT PLANNING, ORDERING FABRICATION AND ASSEMBLY OF HARDWARE
- DIRECT PLANNING, ORDERING, AND FABRICATION OF TEST EQUIPMENT AND TEST FUNCTIONS
- PROVIDE SUPPORT TO STET AND LAUNCH OPERATIONS

MATERIEL MANAGER

- MAINTAIN ETHICAL AND COMPETITIVE PROCUREMENT SYSTEM
- BE SOLE COMMITMENT AUTHORITY FOR PROCUREMENT
- MAINTAIN INVENTORY MANAGEMEN
- MAINTAIN SOURCE SELECTION SYSTEM
- ESTABLISH INCOMING TRAFFIC ROUTING
- ACCOMPLISH RECEIVAL AND STORAGE OF PARTS
- FURNISH MAKE-OR-BUY SUPPORT

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SYSTEM ENGINEERING

S. R. RAGAR

- DEVELOP SPACECRAFT CONSTRAINTS
- CONDUCT SYSTEM-LE STUDIES TO OPTIMIZE SYSTEM
- DEVELOP SPACECRAFT FUNCTIONAL DESCRIP
- DEVELOP TEST REQUIRE SPACECRAFT SYSTEM

QUALITY CONTROL MANAGER

- ESTABLISH & DIRECT QUALITY CONTROL REQUIREMENTS AND PROCEDURES
- DEVELOP QUALITY CONTROL PLAN TO COMPLY WITH NPC 200-2
- DIRECT PRODUCT INSPECTION & QUALITY ENGINEERING ACTIVITIES
- PROVIDE ACCOUNTABILITY RECORD SYSTEM & DISCREPANCY CONTROL SYSTEM

SYSTEM REQUIREMENTS

- ESTABLISH SPACECRAFT AND OSE DESIGN OBJECTIVES
- ESTABLISH SPACECRAFT AND OSE REQUIREMENTS AND CONSTRAINTS
- DEVELOP SPACECRAFT TEST REQUIREMENTS
- ESTABLISH SPACECRAFT SYSTEM INTERFACE REQUIREMENTS
- MONITOR DESIGN COMPLIANCE
- MONITOR INTEGRATED TEST PLAN

SYSTEM ANALYSIS

- CONDUCT SYSTEM-LEVEL OPTIMIZATION AND TRADE STUDIES
- ASSIST IN SELECTION OF PREFERRED SPACECRAFT DESIGN
- CONDUCT SYSTEM-LEVEL FAILURE MODE ANALYSIS

SYSTEM INT

- ESTABLISH FUNCTIO MISSION EVENTS
- DEVELOP SPACECRA DESCRIPTIONS
- PREPARE SPACECRAF SPECIFICATIONS
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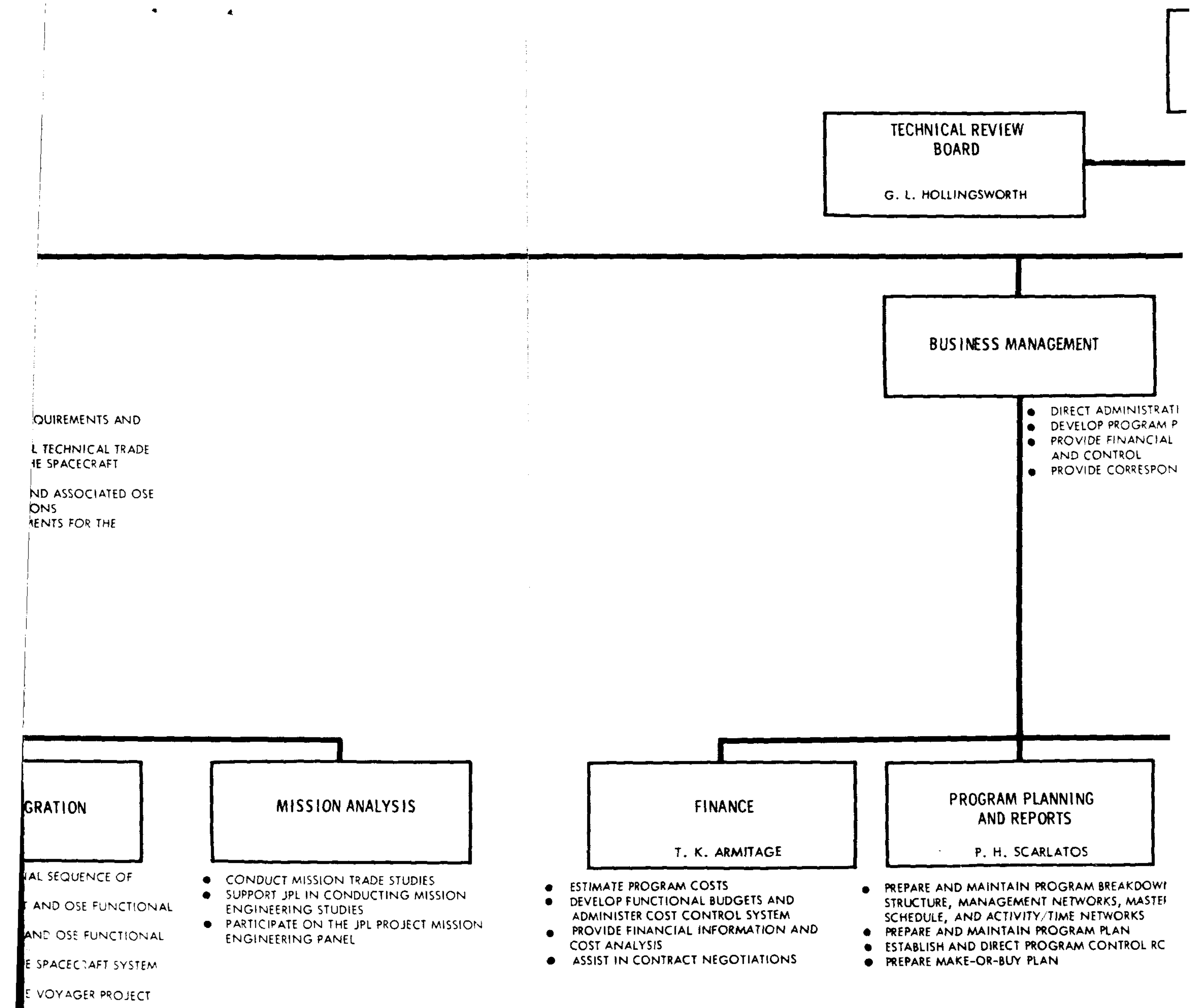
TECHNICAL REVIEW BOARD
G. L. HOLLINGSWORTH
BUSINESS MANAGEMENT
DIRECT ADMINISTRATI
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MISSION ANALYSIS
CONDUCT MISSION TRADE STUDIES
SUPPORT JPL IN CONDUCTING MISSION ENGINEERING STUDIES
PARTICIPATE ON THE JPL PROJECT MISSION ENGINEERING PANEL
FINANCE
T. K. ARMITAGE
ESTIMATE PROGRAM COSTS
DEVELOP FUNCTIONAL BUDGETS AND ADMINISTER COST CONTROL SYSTEM
PROVIDE FINANCIAL INFORMATION AND COST ANALYSIS
ASSIST IN CONTRACT NEGOTIATIONS
PROGRAM PLANNING AND REPORTS
P. H. SCARLATOS
PREPARE AND MAINTAIN PROGRAM BREAKDOWI STRUCTURE, MANAGEMENT NETWORKS, MASTEI SCHEDULE, AND ACTIVITY/TIME NETWORKS
PREPARE AND MAINTAIN PROGRAM PLAN
ESTABLISH AND DIRECT PROGRAM CONTROL RC
PREPARE MAKE-OR-BUY PLAN

VOYAGER SPACECRAFT SYSTEM PROGRAM MANAGER
E. G. CZARNECKI

ASSISTANT PROGRAM MANAGER PASADENA RESIDENT

ON OF CONTRACTS FUNCTION
ANS AND DIRECTIVES
ND RESOURCE DIRECTION

ENCE CONTROL

PLANETARY QUARANTINE
J. A. STERN

- IDENTIFY AND ESTABLISH PLANETARY QUARANTINE REQUIREMENTS AND CONSTRAINTS
- DIRECT PLANETARY QUARANTINE ACTIVITIES
- CERTIFY END-PRODUCT COMPLIANCE WITH PLANETARY QUARANTINE REQUIREMENTS

PRODUCT ASSURANCE
C. S. BARTHOLOMEW

- ESTABLISH AND DIRECT IMPLEMENTATION OF POLICIES, PLANS, REQUIREMENTS, BUDGETS, AND PROCEDURES FOR PROGRAM RELIABILITY, SAFETY, QUALITY ASSURANCE, AND CONFIGURATION MANAGEMENT ACTIVITIES
- DIRECT ESTABLISHMENT AND MONITORING OF SUBCONTRACTOR PRODUCT ASSURANCE FUNCTIONS
- ESTABLISH AND DIRECT PRODUCT ASSURANCE DATA CENTRAL FUNCTION

CONTRACT ADMINISTRATION
H. R. SYVERSON

- DIRECT ADMINISTRATION & NEGOTIATION OF CONTRACTS
- SUBMIT & NEGOTIATE PROPOSALS TO CHANGE CONTRACT STATEMENT OF WORK
- DEVELOP FUNCTIONAL WORK STATEMENTS
- ACCOUNT AND REPORT CONTRACT TASK COMPLETIONS
- CONTROL CONTRACTUAL CORRESPONDENCE

OM

RELIABILITY & SAFETY

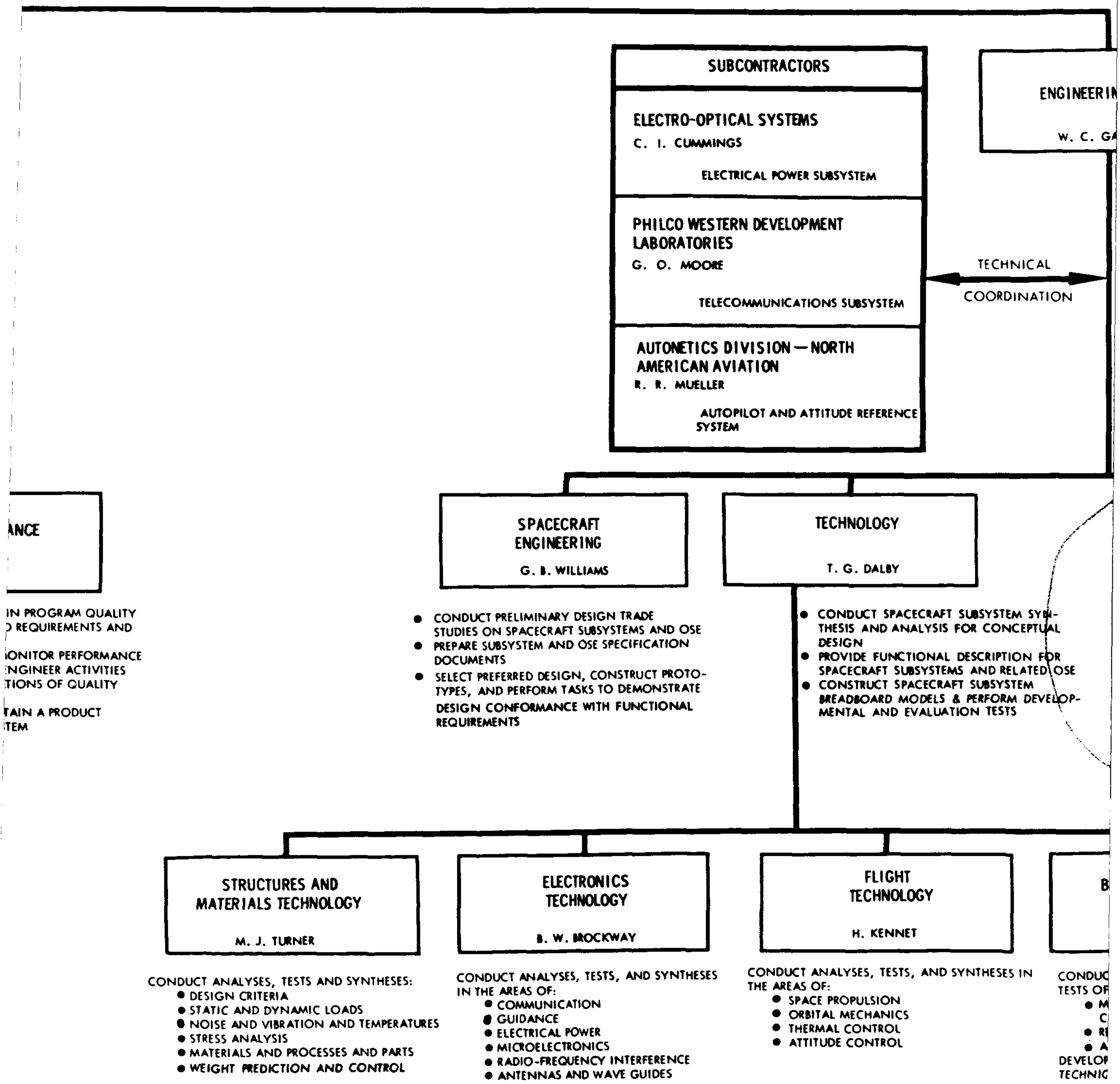
- PREPARE AND MAINTAIN RELIABILITY AND SAFETY REQUIREMENTS, PROGRAM PLANS, PROCEDURES, AND CONTROLS
- ASSIGN RELIABILITY AND SAFETY TASKS, PERFORM INVESTIGATIONS, AND MONITOR AND REPORT PERFORMANCE
- PREPARE SUBCONTRACTOR RELIABILITY AND SAFETY REQUIREMENTS AND MONITOR PERFORMANCE
- OPERATE A SAFETY OFFICE
- ESTABLISH RELIABILITY TEST REQUIREMENTS AND INCLUDE TEST RESULTS IN PERIODIC RELIABILITY STATUS REPORTING

CONFIGURATION MANAGEMENT

- ENSURE PROPER IDENTIFICATION CONTROL IS MAINTAINED OF CONTRACT DELIVERABLE END ITEMS
- ESTABLISH AND MAINTAIN AN ENGINEERING RELEASE AND RECORDS CONTROL SYSTEM
- ENSURE PROPER ACCOUNTABILITY CONTROL IS MAINTAINED
- MAINTAIN CONFIGURATION CONTROL CENTER AND CHANGE BOARD

QUALITY ASSUR

- PREPARE AND MAINT ASSURANCE PLAN AN AUDIT PERFORMANCE
- ASSIGN TASKS AND
- DIRECT COGNIZANT
- CONDUCT INVESTIG PROBLEMS
- ESTABLISH AND MAIN ASSURANCE DATA SY


SUBCONTRACTORS
ELECTRO-OPTICAL SYSTEMS
C. I. CUMMINGS
ELECTRICAL POWER SUBSYSTEM
PHILCO WESTERN DEVELOPMENT LABORATORIES
G. O. MOORE
TELECOMMUNICATIONS SUBSYSTEM
AUTONETICS DIVISION — NORTH AMERICAN AVIATION
R. R. MUELLER
AUTOPILOT AND ATTITUDE REFERENCE SYSTEM
TECHNICAL COORDINATION
ENGINEERIN
W. C. G
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IN PROGRAM QUALITY
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SPACECRAFT ENGINEERING
G. B. WILLIAMS
CONDUCT PRELIMINARY DESIGN TRADE STUDIES ON SPACECRAFT SUBSYSTEMS AND OSE
PREPARE SUBSYSTEM AND OSE SPECIFICATION DOCUMENTS
SELECT PREFERRED DESIGN, CONSTRUCT PROTOTYPES, AND PERFORM TASKS TO DEMONSTRATE DESIGN CONFORMANCE WITH FUNCTIONAL REQUIREMENTS
TECHNOLOGY
T. G. DALBY
CONDUCT SPACECRAFT SUBSYSTEM SYNTHESIS AND ANALYSIS FOR CONCEPTUAL DESIGN
PROVIDE FUNCTIONAL DESCRIPTION FOR SPACECRAFT SUBSYSTEMS AND RELATED OSE
CONSTRUCT SPACECRAFT SUBSYSTEM BREADBOARD MODELS & PERFORM DEVELOPMENTAL AND EVALUATION TESTS
STRUCTURES AND MATERIALS TECHNOLOGY
M. J. TURNER
CONDUCT ANALYSES, TESTS AND SYNTHESES:
DESIGN CRITERIA
STATIC AND DYNAMIC LOADS
NOISE AND VIBRATION AND TEMPERATURES
STRESS ANALYSIS
MATERIALS AND PROCESSES AND PARTS
WEIGHT PREDICTION AND CONTROL
ELECTRONICS TECHNOLOGY
B. W. BROCKWAY
CONDUCT ANALYSES, TESTS, AND SYNTHESES IN THE AREAS OF:
COMMUNICATION
GUIDANCE
ELECTRICAL POWER
MICROELECTRONICS
RADIO-FREQUENCY INTERFERENCE
ANTENNAS AND WAVE GUIDES
FLIGHT TECHNOLOGY
H. KENNET
CONDUCT ANALYSES, TESTS, AND SYNTHESES IN THE AREAS OF:
SPACE PROPULSION
ORBITAL MECHANICS
THERMAL CONTROL
ATTITUDE CONTROL
CONDUC
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AVAILABLE SCIENTIFIC CONSULTANTS

NAME	SPECIALTY	AFFILIATION
DR. Z. KOPAL	PLANETARY ASTRONOMY	U. OF MANCHESTER, ENGLAND
DR. G. DEVANCOULEURS	ASTRONOMY AND MARTIAN AUTHORITY	U. OF TEXAS
DR. A. DEPRIT	TRAJECTORIES AND CELESTIAL MECHANICS	BOEING SCIENTIFIC RESEARCH LAB.
DR. C. L. GOUDAS	PLANETARY GRAVITATIONAL PERTURBATIONS	BOEING SCIENTIFIC RESEARCH LAB.
DR. J. F. KENNEY	SCIENTIFIC INVESTIGATIONS, INSTRUMENTATION	BOEING SCIENTIFIC RESEARCH LAB.
DR. D. L. JOHNSON	LINEAR PROGRAMMING	BOEING SCIENTIFIC RESEARCH LAB.
DR. R. I. SCHOEN	UPPER ATMOSPHERE, PLASMA PHYSICS, AND SOLID STATE PHYSICS	BOEING SCIENTIFIC RESEARCH LAB.
J. M. SAARI	MASS SPECTROMETERS AND OTHER INSTRUMENTATION	BOEING SCIENTIFIC RESEARCH LAB.

ANAGER

WAY

- DIRECTS ALL DESIGN AND DEVELOPMENT OF THE SPACECRAFT AND OSE
- PROVIDES SUBCONTRACTOR TECHNICAL DIRECTION AND COORDINATION
- DIRECT SCIENCE SUBSYSTEM INTEGRATION
- DIRECTS LAUNCH VEHICLE INTEGRATION
- DIRECTS FLIGHT CAPSULE INTEGRATION

SPACE SCIENCE INTEGRATION

W. F. HILTNER

BTAIN SCIENCE SUBSYSTEM DESCRIP-IONS & SPACIFY REQUIREMENTS ON PACECRAFT DESIGN
EFINE THE ELECTRICAL INTERFACE BETWEEN HE DATA AUTOMATION CONDITIONING YSTEM AND THE CC&S
EVELOP TEST REQUIREMENTS

LOGISTICS

- ESTABLISH LOGISTIC SUPPORT CRITERIA, OBJECTIVES, AND GOALS
- ACCOMPLISH SUPPORT SYSTEM ANALYSIS AND DEVELOP LOGISTICS PLANS
- DETERMINE SUPPORT SYSTEM REQUIREMENTS INCLUDING SPARES, PUBLICATIONS TRAINING EQUIPEMENT, MAINTAINABILITY AND TRANSPORTATION

STRONAUTICS

J. PILGRIM

RILIZATION ANALYSIS AND
IOLOGICAL LOAD AND BIO-
OPERATIONS
RY TECHNIQUES
TECHNIQUES
LIZATION MONITORING

Figure 2: Boeing Voyager Spacecraft System Management Structure

7

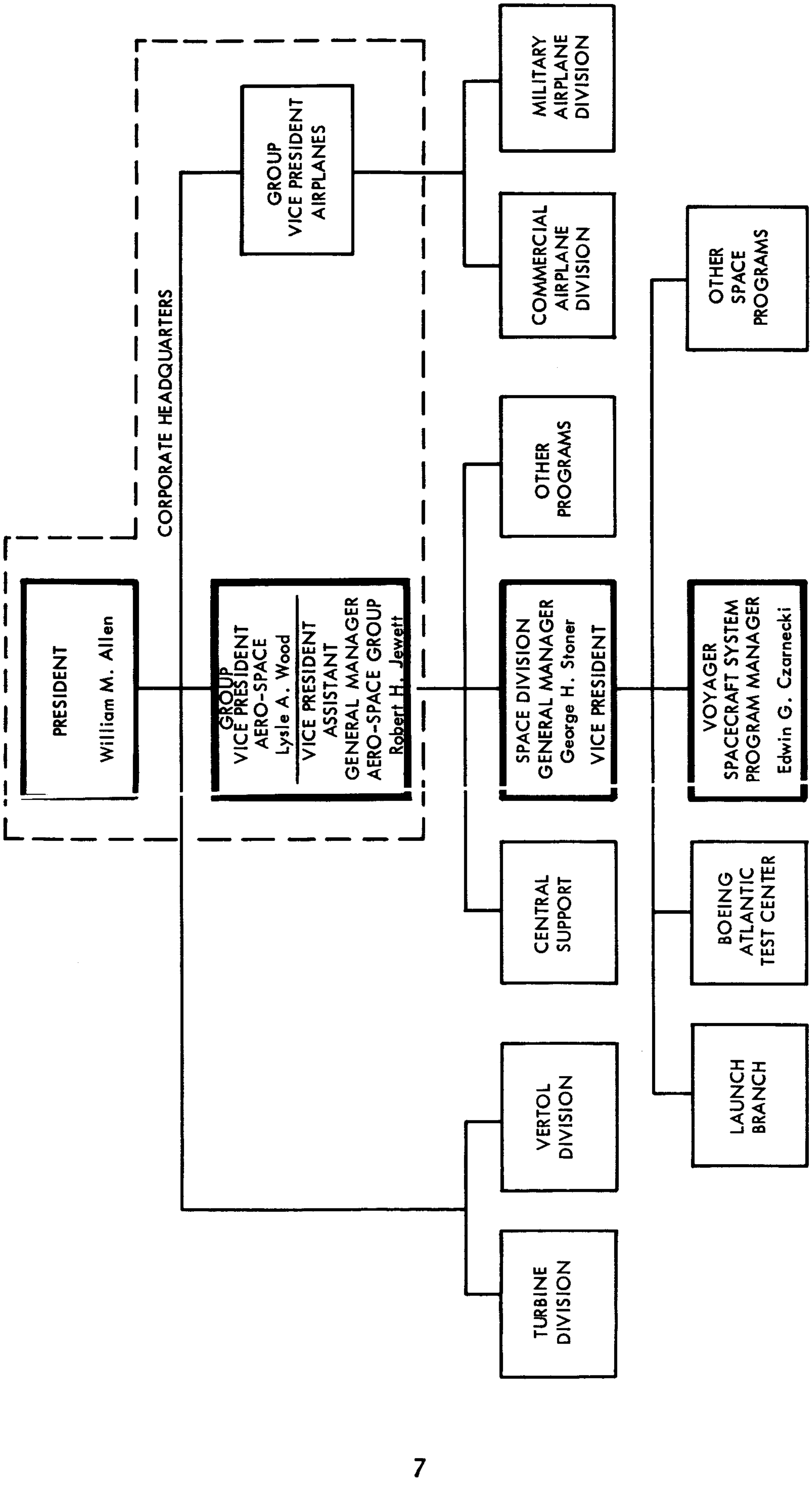


Figure 3: The Boeing Company — Planned Organization

operating division will become essentially autonomous, drawing upon the Central Support Services for support involving specialized or one-of-a-kind facilities or services that are not economical to assign to a single division.

In keeping with this concept, the new Space Division, under the direction of Mr. Stoner, vice-president and general manager, will be assigned facilities of the company which are directly pertinent to space-oriented activities. When planned facilities become available, the headquarters of the Space Division will be established at the Boeing Space Center, Kent, Washington. Mr. Stoner's office would be located at this facility as would Mr. Czarnecki, the Voyager program management team, and other spacecraft programs of the division. All major spacecraft programs would thus be afforded a consolidated assembly, test, and management complex from which the specialized management concepts and product assurance measures unique to space programs could be administered efficiently and effectively.

The Space Division will be supported by other resources of the company as may be required under direct control of the Space Division or the Central Support activity, and thereby accessible to the Voyager program manager, Mr. Czarnecki. Space-oriented capabilities potentially pertinent to the Voyager program are:

- The Boardman Test Site, Oregon;
- The Huntsville Simulation Center and Electronics Engineering Organization;
- The Hazardous Test Site, Tulalip, Washington;
- The Boeing Atlantic Test Center, Cape Kennedy;
- The 2.01 Office and Laboratory Complex in Seattle (where Mr. Czarnecki's Voyager program activities are currently forming and building).

THE MANAGEMENT JOB

Boeing's experience in the management of major systems has involved the planning and integration of the efforts of subcontractors, associate contractors, and government agencies at many widely separated geographical areas, and provides the understanding and capability necessary to analyze, plan, and accomplish the Voyager program. The organization, methods, and the personnel committed by Boeing for Voyager are the result of a thorough analysis of the program's requirements, during which the following were identified:

- How JPL will procure and manage the program;
- Precisely what the management job is, how it will be broken down by function, where these functions will be accomplished, and how they will be accomplished;
- The type of organization necessary to accomplish the management job;
- The management methods and organization relationships necessary to accomplish the job;

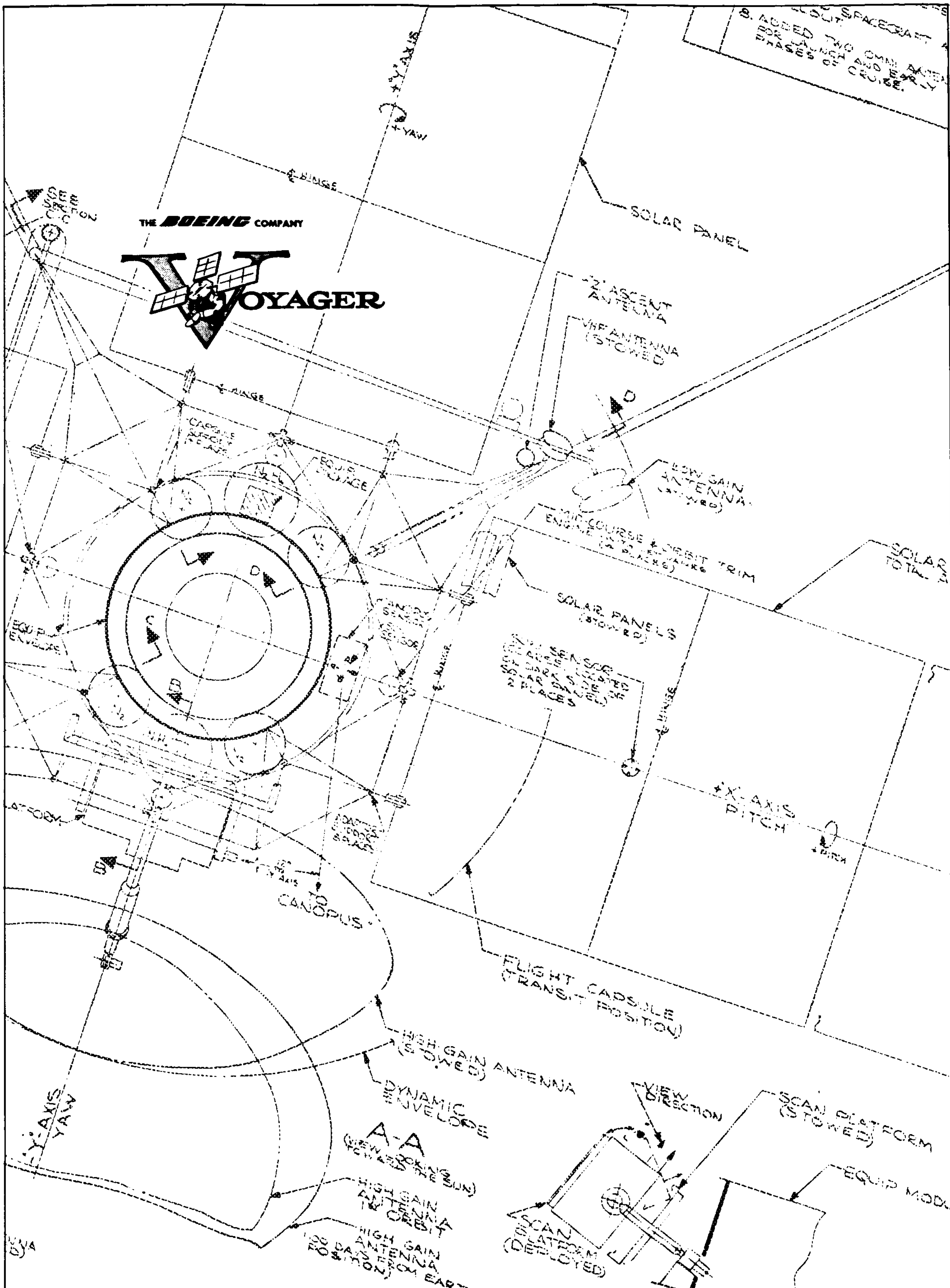
- The technical/management team of experienced personnel who can accomplish JPL's objectives and are committed to this program.

The total Voyager management job, illustrated in summary form in Figure 4 and culminating in the mission shown in Figure 5, can be divided into four major categories of work as follows:

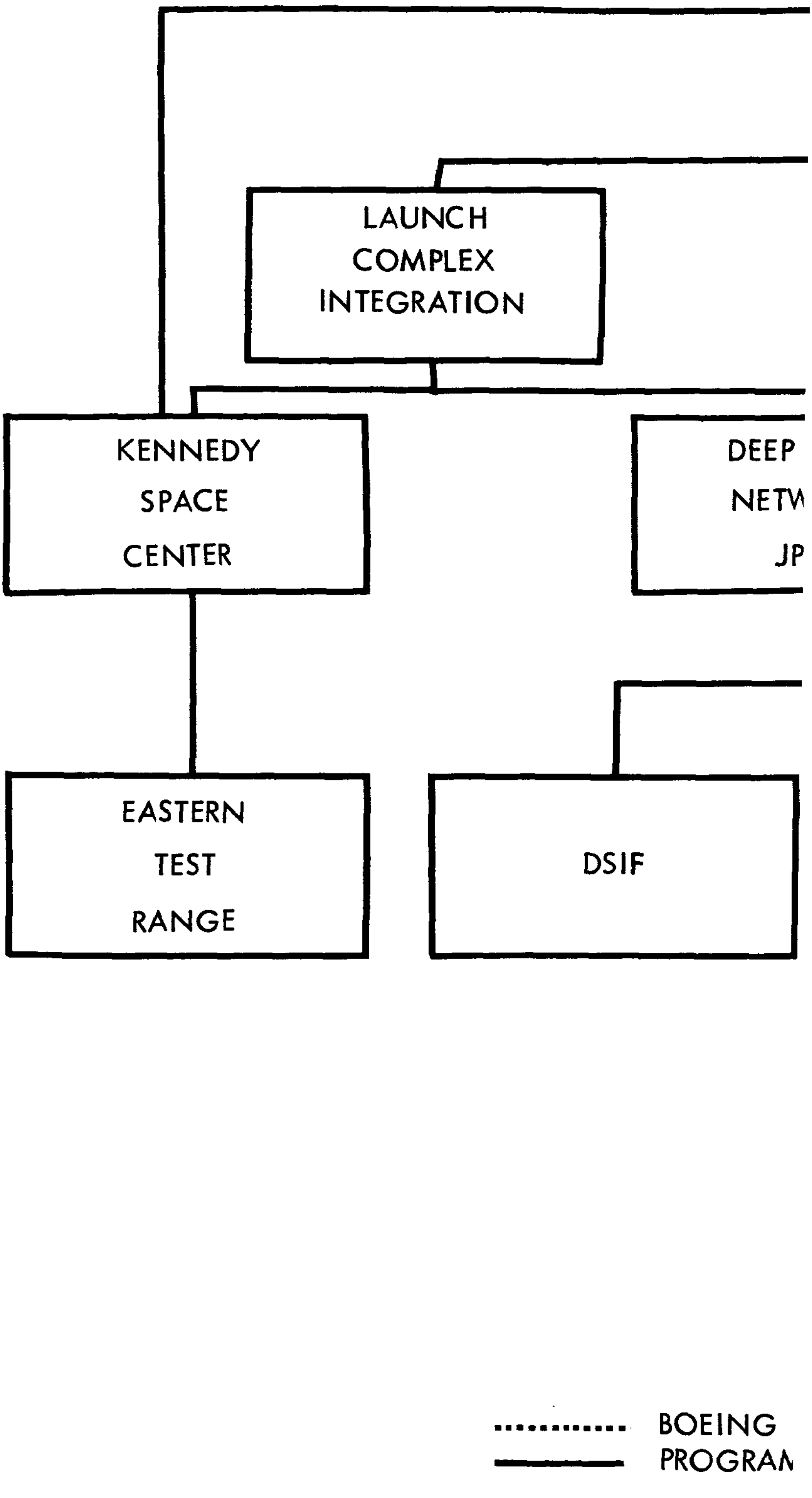
- The overall Voyager program management, planning, system integration, and implementation;
- The management and planning necessary to provide the integrated flight spacecraft and space Science Payload;
- The management and planning necessary to provide the booster system and its integration with the launch complex;
- The management and planning necessary to integrate the launch complex and deep-space network and conduct the launch, mission, and data-recovery operations.

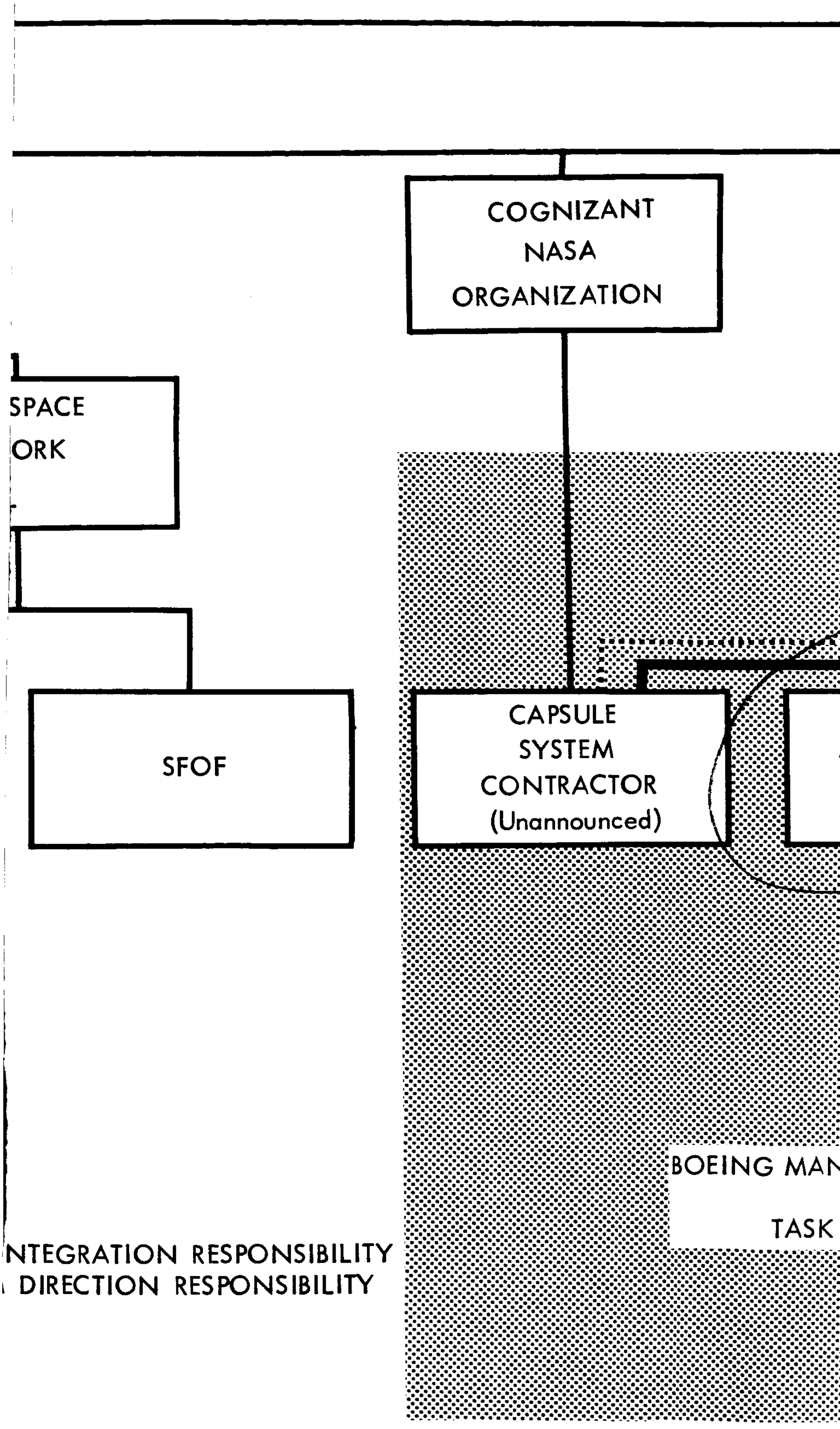
The work to be accomplished for each of the above categories involves the integration of government and industry personnel and facilities at widely separated geographical areas, namely:

- JPL facilities in Pasadena, California, where the Voyager program will be planned and managed;
- Boeing facilities in Kent, Washington, where the spacecraft/Science Payload integration task will be planned and managed, and the spacecraft and ground support equipment development, fabrication, assembly, and test will be accomplished;
- The government facilities at Michoud, Louisiana, where the Saturn S-IB booster and ground support equipment development, fabrication, assembly, and test will be accomplished by Chrysler Corporation;
- The Douglas Missile and Space Systems Division facilities in Santa Monica, California, where the Saturn IV and ground support equipment development, fabrication, assembly, and test will be accomplished;
- The Convair facilities in San Diego, California, where the Centaur and ground support equipment development, fabrication, assembly, and test will be accomplished;
- The ETR launch site at Cape Kennedy, where the Voyager spacecraft will be delivered; integrated with the Science Payload, Saturn S-IB, Centaur, and the launch complex; and launched;
- The Space Flight Operations Facility (SFOF) at Pasadena, California, where command control will be exercised during launch, mission, and data-recovery operations;
- The world-wide Deep-Space Instrumentation Facility (DSIF), consisting of tracking and communication stations at Goldstone, California; Madrid, Spain; and Woomera, Australia; these stations will provide command, telemetry, and position tracking of the spacecraft during its mission.

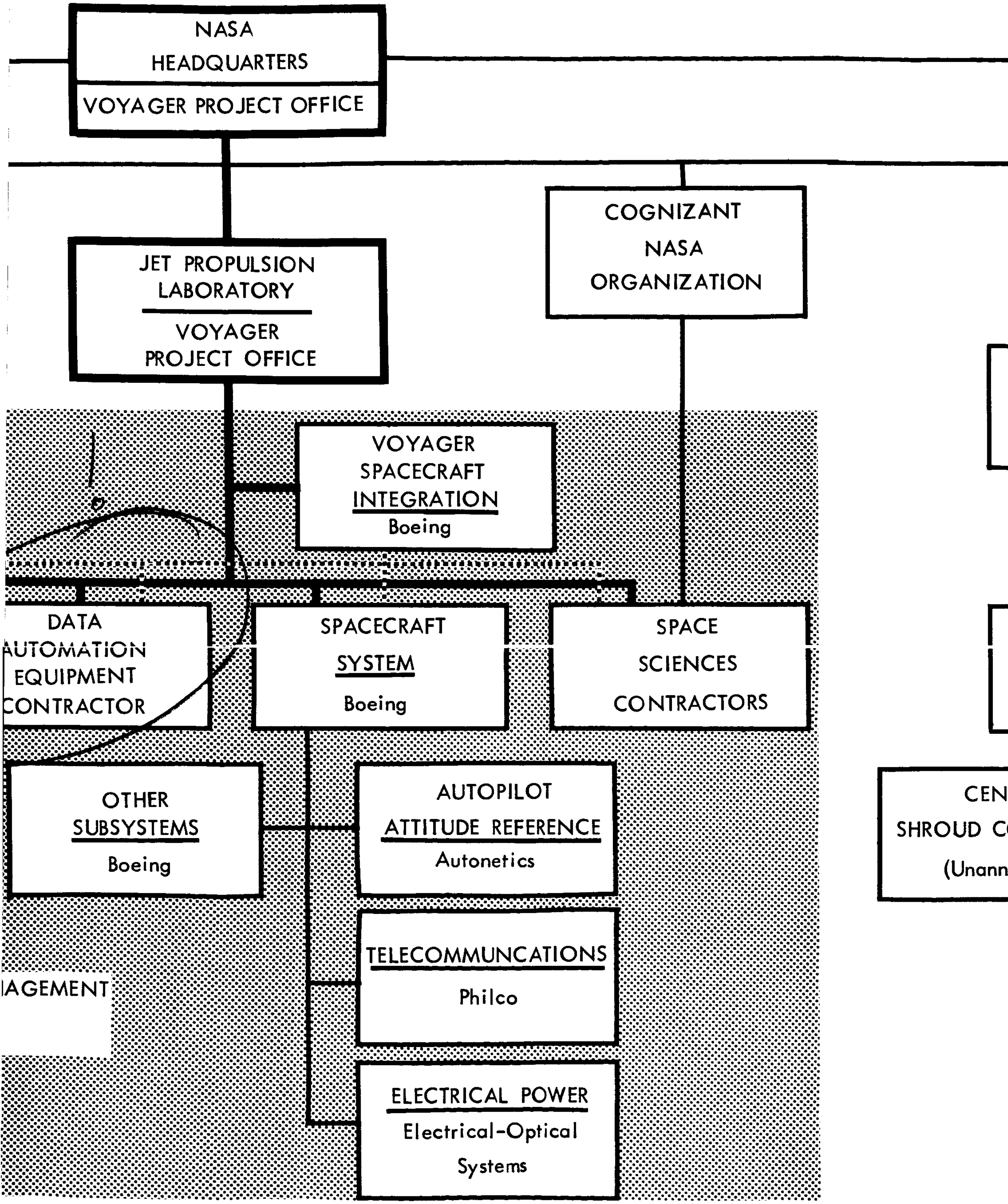


THE BOEING COMPANY
VOYAGER
+Y AXIS
+YAW
SOLAR PANEL
ASCENT ANTENNA
VHF ANTENNA (STOWED)
LOW GAIN ANTENNA (STOWED)
EQUIP PACKAGE
EQUIP ENVELOPE
SOLAR PANELS (STOWED)
+X AXIS PITCH
TO CANOPUS
FLIGHT CAPSULE (TRANSIT POSITION)
HIGH GAIN ANTENNA (STOWED)
DYNAMIC ENVELOPE
-Y AXIS YAW
A-A
HIGH GAIN ANTENNA IN ORBIT
VIEW DIRECTION
SCAN PLATFORM (STOWED)
SCAN PLATFORM (DEPLOYED)


LAUNCH COMPLEX INTEGRATION
KENNEDY SPACE CENTER
DEEP
NETW
JP
EASTERN TEST RANGE
DSIF
BOEING
PROGRAM


COGNIZANT NASA ORGANIZATION
SPACE
ORK
SFOF
CAPSULE SYSTEM CONTRACTOR (Unannounced)
BOEING MAN
TASK
NTEGRATION RESPONSIBILITY
DIRECTION RESPONSIBILITY

2


NASA HEADQUARTERS
VOYAGER PROJECT OFFICE
JET PROPULSION LABORATORY
VOYAGER PROJECT OFFICE
COGNIZANT NASA ORGANIZATION
VOYAGER SPACECRAFT INTEGRATION
Boeing
DATA AUTOMATION EQUIPMENT CONTRACTOR
SPACECRAFT SYSTEM
Boeing
SPACE SCIENCES CONTRACTORS
OTHER SUBSYSTEMS
Boeing
AUTOPILOT ATTITUDE REFERENCE
Autonetics
TELECOMMUNCATIONS
Philco
ELECTRICAL POWER
Electrical-Optical Systems
AGEMENT
CEN
SHROUD C
(Unann

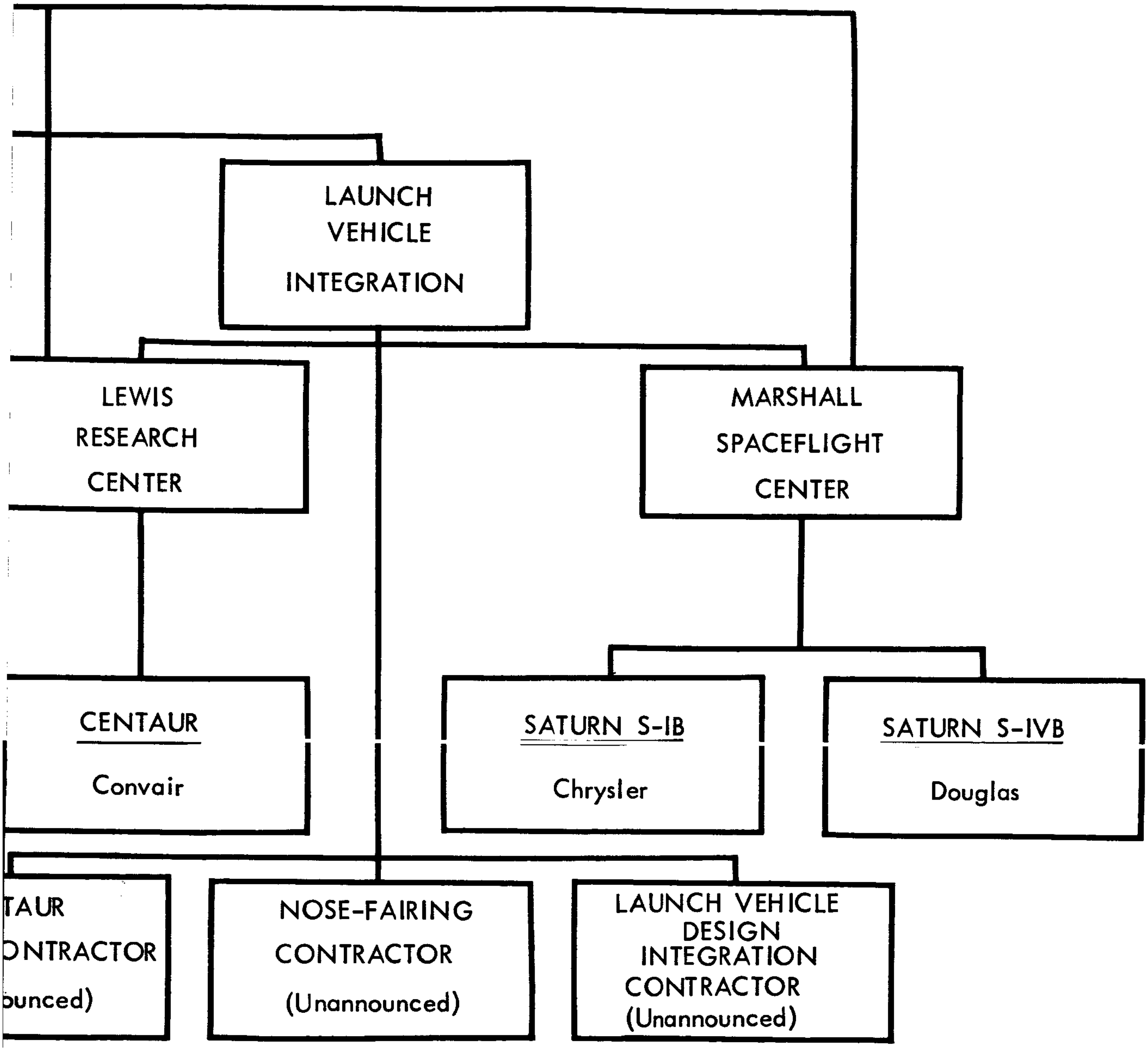
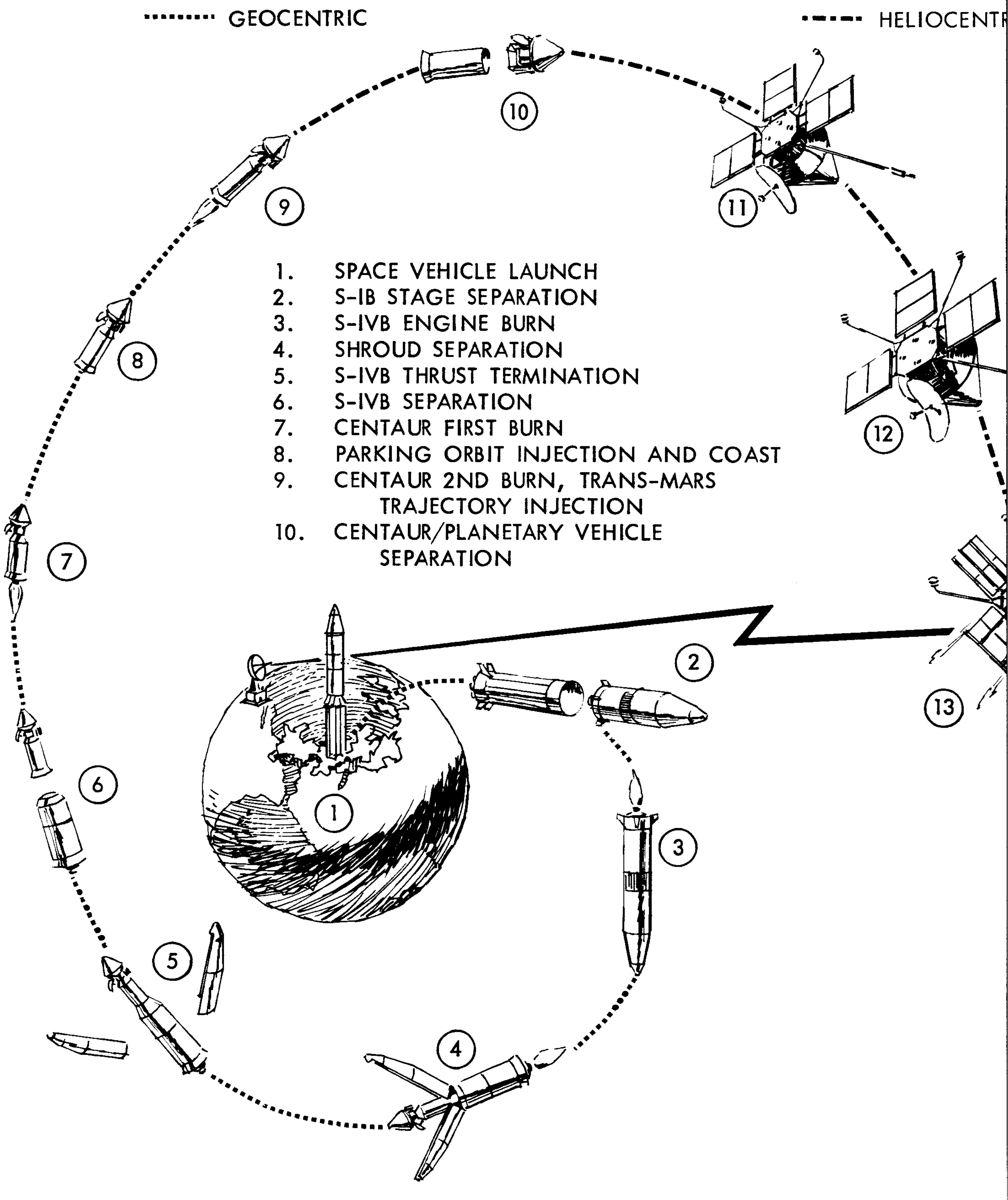


Figure 4: TOTAL VOYAGER MANAGEMENT JOB

4


GEOCENTRIC
HELIOCENTR
1. SPACE VEHICLE LAUNCH
2. S-IB STAGE SEPARATION
3. S-IVB ENGINE BURN
4. SHROUD SEPARATION
5. S-IVB THRUST TERMINATION
6. S-IVB SEPARATION
7. CENTAUR FIRST BURN
8. PARKING ORBIT INJECTION AND COAST
9. CENTAUR 2ND BURN, TRANS-MARS TRAJECTORY INJECTION
10. CENTAUR/PLANETARY VEHICLE SEPARATION
1
2
3
4
5
6
7
8
9
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11
12
13

RIC

——— AREOCENTRIC

11. DEPLOYMENT SOLAR PANELS & ANTENNAS. ACQUISITION OF CELESTIAL REFERENCES.
12. PLANETARY VEHICLE CRUISE
13. INTERPLANETARY TRAJECTORY CORRECTIONS
14. CAPSULE-FLIGHT SPACECRAFT SEPARATION
15. FLIGHT SPACECRAFT CRUISE
16. CAPSULE TRAJECTORY DEFLECTION, CRUISE, ENTRY, AND DESCENT
17. CAPSULE LANDING & OPERATIONS
18. FLIGHT SPACECRAFT ORBIT INSERTION
19. FLIGHT SPACECRAFT ORBITAL OPERATION

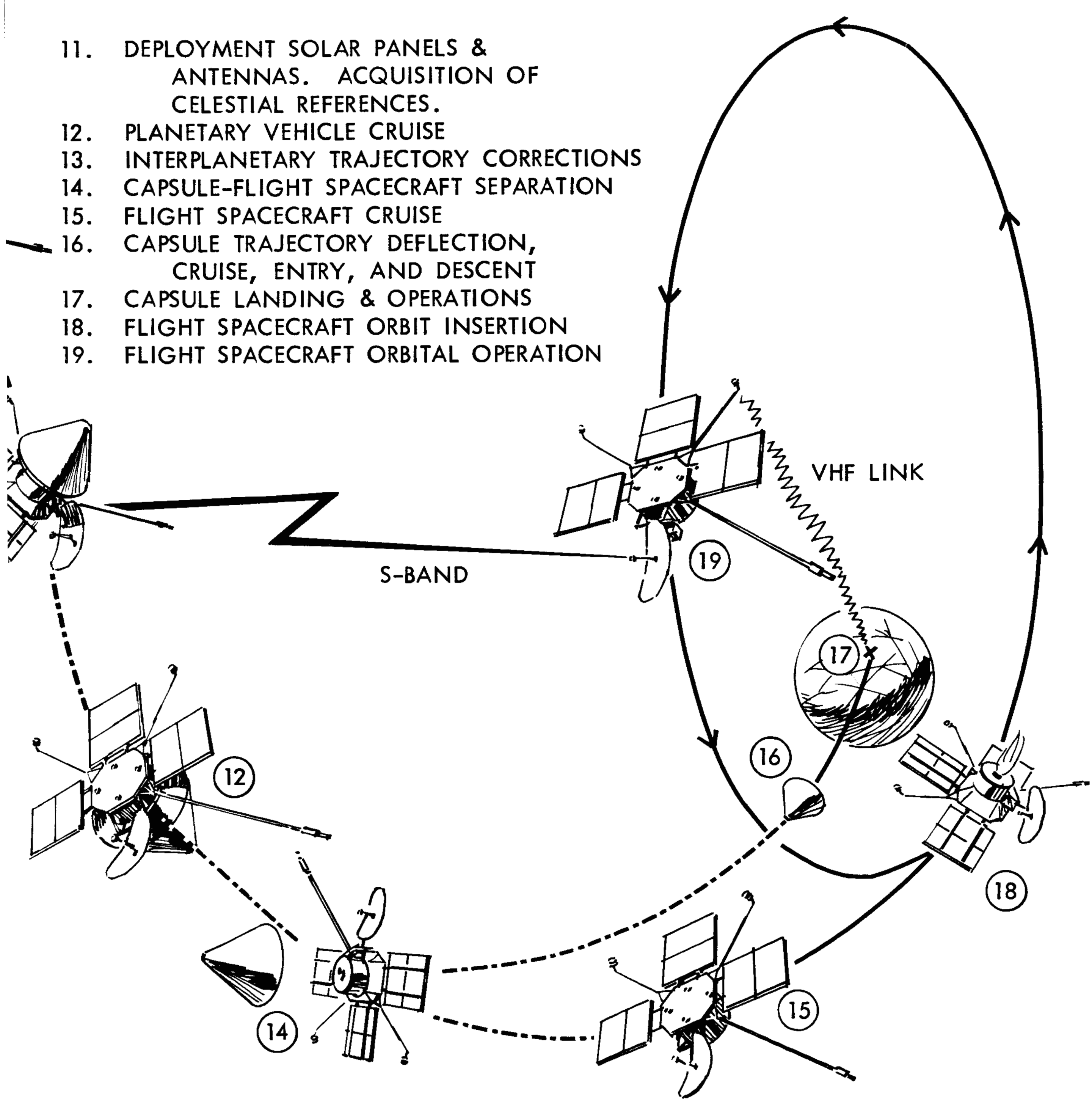


Figure 5: Voyager Mission Profile

2

THE INDUSTRIAL TEAM

Although Boeing has technical management capability in all aspects of the Voyager program, it is planned to extend this capability in depth through association with companies recognized as specialists in certain fields. Use of team members to strengthen Boeing's capability was considered during the preproposal period. The basic concept was to add team members who would complement Boeing experience and capability, and significantly improve the amount and quality of technical and management activities. Boeing's long-term program in research, technology, and design has been directed to complex space systems, and has involved extensive contacts with industry in many technical areas. As a result of these contacts, Boeing has developed a good understanding of the technical competence available within industry for application to the Voyager program. Areas of potential need were identified, and data was obtained from companies possessing recognized capability in desired technologies. Based on competitive considerations, including experience with JPL programs and past performance, and giving strongest emphasis to technical qualifications and management willingness to support Voyager, Autonetics, Philco Western Development Laboratories, and Electro-Optical Systems, Inc., were chosen as team members. This team arrangement, subject to JPL approval, is shown in Figure 6.

VOYAGER SPACECRAFT AND SPACE SCIENCES PAYLOAD INTEGRATION CONTRACTOR The Boeing Company Seattle, Washington Mr. E. C. Czarnecki — Program Manager		
SUBCONTRACTOR	SUBCONTRACTOR	SUBCONTRACTOR
Autonetics North American Aviation Anaheim, California	Philco, Western Development Lab. Palo Alto, California	Electro-Optical Systems, Inc. Pasadena, California
● Autopilot and Attitude Reference	● Telecommunication Subsystem	● Electrical Power Subsystem
Mr. R. R. Mueller Program Manager	Mr. G. O. Moore Program Manager	Mr. C. I. Cummings Program Manager

Figure 6: BOEING VOYAGER TEAM

The Flight Spacecraft design and integration task to be accomplished by this team is illustrated in Figure 7. Formal work-statement agreements have been arrived at and, as a result, there has been a continuous and complete free exchange of information and documentation among all team members. The considerable technical background developed since the above associations were arrived at and the professional and personal rapport established between individual team members has made it possible for Boeing, Autonetics, Philco. and Electro-Optical Systems to arrive at an understanding covering each team member's responsibility in the Voyager program. This understanding establishes interface relationships and modes of operation making it possible for:

- Immediate discussions with JPL, permitting early negotiation of contract terms and immediate implementation of the program;
- The Boeing team to satisfy JPL requirements in depth and with confidence.

Boeing, Autonetics, Philco, and Electro-Optical Systems have the experienced personnel, facilities, and financial capability to accomplish the Voyager program.

The experience and background of the executives appointed by each team company to discharge that company's responsibilities follow.

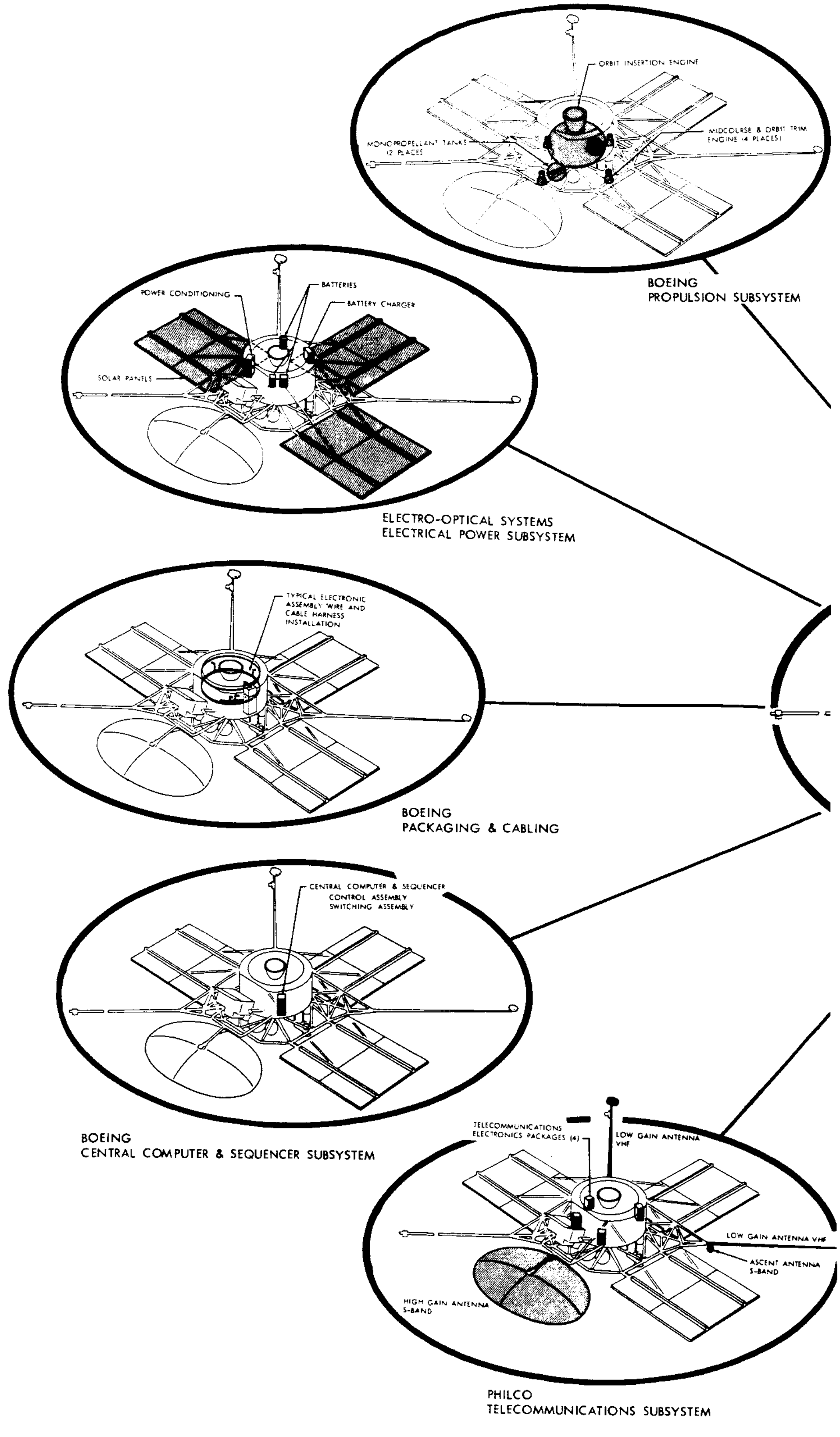
- Boeing Voyager Program Manager — Edwin G. Czarnecki

B.S., Aeronautical Engineering, University of Alabama.

Mr. Czarnecki has been associated with The Boeing Company for 17 years. From 1958 to October 1964, Mr. Czarnecki held high-level management positions as structures and materials technology manager; chief of X-20 technical support; and chief of missile technology, involving the direction of 1000 to 1200 engineering and laboratory personnel. These management assignments have encompassed all technical staff support activities to project design organizations on such programs as Bomarc, Minuteman, X-20, and HiBEX. In addition, he was responsible for research in the technical areas required for ensuring excellence in the support of existing contracts and new-business-acquisition activities. In earlier assignments, from 1953 to 1958, Mr. Czarnecki had structural responsibility for preliminary design work on the 110-A, the Nuclear Airplane, and special weapon systems. During his first 5 years with Boeing, he held lead positions in the structural design of B-47 and 707-80 (707 prototype), and was in charge of Boeing effort concerned with the B-52 special weapons effects. Prior experience included 5 years with Chance-Vought, where he was an assistant project structural engineer. Mr. Czarnecki has presented many papers to technical societies in the United States and abroad, and has had several articles published. He is an associate fellow of AIAA; former chairman of Pacific Northwest Section — AIAA; member of NASA Research Advisory Committee on Space Vehicle Structures; and has served on National Academy of Science and on ARS committees.

- Autonetics Program Manager — Rudy R. Mueller

B.S., Mechanical Engineering, University of Texas.
M.S., Theoretical and Applied Mechanics, University of Texas.


ORBIT INSERTION ENGINE
MONOPROPELLANT TANKS (2 PLACES)
MIDCOURSE & ORBIT TRIM ENGINE (4 PLACES)
BOEING
PROPULSION SUBSYSTEM
POWER CONDITIONING
BATTERIES
BATTERY CHARGER
SOLAR PANELS
ELECTRO-OPTICAL SYSTEMS
ELECTRICAL POWER SUBSYSTEM
TYPICAL ELECTRONIC ASSEMBLY WIRE AND CABLE HARNESS INSTALLATION
BOEING
PACKAGING & CABLING
CENTRAL COMPUTER & SEQUENCER
CONTROL ASSEMBLY
SWITCHING ASSEMBLY
BOEING
CENTRAL COMPUTER & SEQUENCER SUBSYSTEM
TELECOMMUNICATIONS ELECTRONICS PACKAGES (4)
LOW GAIN ANTENNA VHF
LOW GAIN ANTENNA VHF
ASCENT ANTENNA S-BAND
HIGH GAIN ANTENNA S-BAND
PHILCO
TELECOMMUNICATIONS SUBSYSTEM

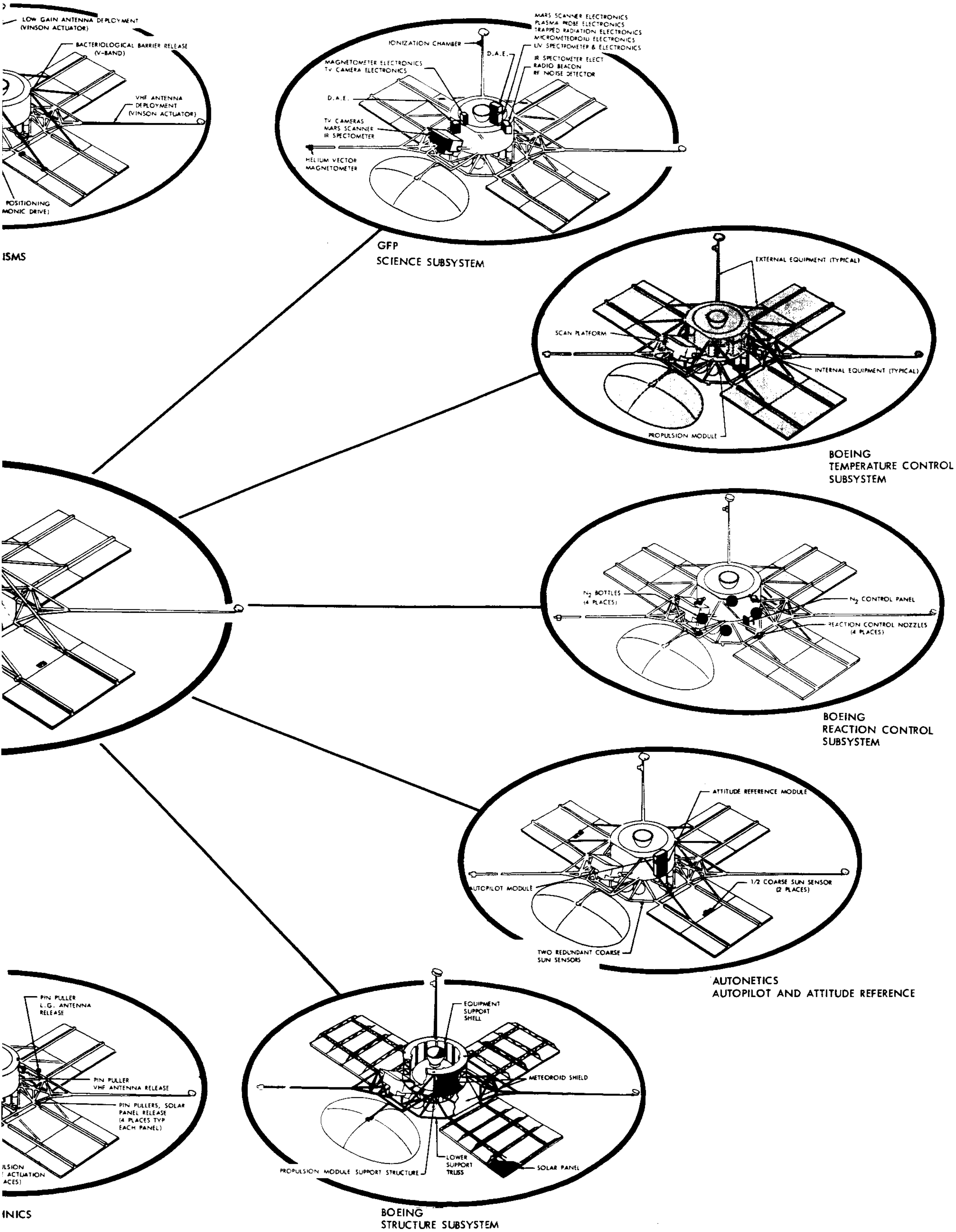


Figure 7 Voyager Flight Spacecraft Subsystem Integration

Mr. Mueller has been with North American for 8 years, and has been engaged in technical and management responsibilities in the space field throughout almost all of this period. Prior to his assignment as Voyager program manager, he served as project engineer for these Autonetics programs: Voyager Design Studies, the Lunar Logistics System, and the Logistics Spacecraft. Prior to 1957, he taught at the University of Texas and held engineering positions with Convair and Chance-Vought. He has taken a number of postgraduate courses in mathematics and astronautics. Mr. Mueller is a member of Tau Beta Pi, Pi Tau Sigma, the Institute of Navigation Astrodynamics, and the American Institute of Aeronautics and Astronautics, and has participated in lunar and planetary exploration colloquia. Mr. Mueller has presented 12 professional papers in the space field, including, "The Voyager Mission: Guidance and Control Considerations," "An Analysis of Guidance, Navigation, and Control System Equipments for a Mars Mission," and "Investigation of Possible Satellite Position-Sensing Methods." He has also presented a guest lecture at the University of Michigan space seminar.

- Philco Program Manager — Gerald O. Moore

B.S., Electrical Engineering, Purdue University.
Postgraduate work in electronics, space technology, and management training, University of Pennsylvania, University of California, Riches Research Inc.

Mr. Moore has over 25 years of diversified experience with the Philco Corporation in the development of military and consumer communications equipment, including satellite tracking equipment and a complete military communications satellite. In July 1964, he was assigned management responsibility for Philco's planning and contractual efforts for deep-space missions. This responsibility included Advanced Mariner and Voyager studies, a study contract for a Comet and Close Approach Asteroid Mission, a parts-reliability implementation contract, a contract for S-band transponders, and a contract for a nuclear-particle-detection system. He directed the Philco efforts for the USAF Medium-Altitude Communication Satellite (MACS) program and served as director of the Advent Program Office at Western Development Laboratories (WDL), responsible for implementation of telemetry tracking and communication stations. Prior to this, he had managerial responsibility for the entire Courier communications satellite, which was designed and fabricated at WDL. He also supervised the design and development of transmitters and receivers for a large, classified Air Force project. Previous experience included managing Philco's Electronic Division facilities in Mexico City. As a technical consultant with the Philco International Corporation, he was responsible for establishing radio and television assembly operations at various overseas Philco facilities, including those in Argentina, Canada, England, and Israel. While a project engineer with Philco in Philadelphia, he engaged in the development of consumer and military products, including radio proximity fuze for the U.S. Bureau of Standards. Mr. Moore is a senior member of the IEEE and is a member of the AIAA and other professional groups. He has published numerous technical papers, including articles for the IEEE on microwave telemetry and reactance modulated microwave transmitter.

- Electro-Optical Systems, Inc., Program Manager — Clifford I. Cummings

B.S., Physics, California Institute of Technology.
Army Radar Schools, Harvard, and Massachusetts Institute of Technology.

Mr. Cummings has been with Electro-Optical Systems since 1963. Prior to assignment to the Voyager program, he served as manager of program management and systems engineering, responsible for systems analysis, design, integration, test, field operation, and reporting on subsystems and systems developed by EOS as subcontractor or prime contractor in military and space fields. From 1946 to mid-1963, he was employed at the Jet Propulsion Laboratory, serving in his last assignment as special assistant to the director of the laboratory. During the preceding 3.5 years, he was director of the Lunar program. From January 1958 through mid-1959, he was on assignment from JPL to the Weapons System Evaluation Group and the Advanced Research Project Agency, Office of the Secretary of Defense, and to NASA. During the period early 1956 and 1957, he served first as Jupiter project director, responsible for JPL radio guidance effort; and later as division chief of the Systems Engineering Division, with technical and administrative responsibility for three section organizations, including Guidance Systems, Field Operation, and Test and Military and Industrial Services. This involved approximately 250 engineers and technicians. In early JPL assignments, Mr. Cummings was associated for 10 years with the Corporal missile program. From initial responsibility for development of the FM/FM telemetering system, he progressed to Corporal technical coordinator, with responsibility to provide technical coordination of the entire Corporal missile system; this included coordination of the two industrial contractors and the military support and user organizations.

Engineering Development Approach

The character of the Voyager program — one involving a combination of few flight vehicles and relatively long periods between deliveries — will be recognized. The program manager will employ such cost-effective modes of operation as progressive release of engineering drawings, minimum planning for fabrication, assembly, and inspection, the same tooling for test and flight vehicle parts, and use of highly competent personnel in all functional areas.

Integrated Test Program

An integrated test program will be planned and implemented. The goal of this program is to demonstrate the compatibility and reliability of all hardware, and the capability of the spacecraft to operate within design parameters in the expected operational environment, including compatibility with the DSIF. This type of test program is essential at the component, subsystem, and system levels if the reliability of the spacecraft over long unattended periods of flight is to be ensured. A single individual — the systems test and launch operations manager reporting to the program manager — will be responsible for the test program and will ensure the continuity and validity of test data throughout the program.

Spacecraft Technical Management Responsibility

Technical management responsibility for each spacecraft will remain with a single individual from start of spacecraft assembly operations through launch and mission operations.

A spacecraft cognizant engineer, reporting to the systems test and launch operations manager, will be assigned to each ground test spacecraft and flight spacecraft and will provide technical advice to the systems test and launch operations manager during mission operations. The spacecraft engineer will acquaint himself with the systems engineering and design activities, and all test and test results of components and subsystems to be assembled into his spacecraft. At the time of start of final assembly, he will assume responsibility for his spacecraft and will direct the final assembly and system-integration activities and all subsequent tests and checkouts on his spacecraft.

A subsystem cognizant engineer, reporting to the product assurance manager, will be assigned to each subsystem of each spacecraft. He will direct tests on the hardware constituting his subsystem up through subsystem-level testing. At the time of start of final assembly, he will support and start receiving direction from the spacecraft cognizant engineer and will form a part of the spacecraft technical team.

This feature ensures continuous technical responsibility for the spacecraft, and will eliminate accountability problems that often occur as a product is transferred from one organization to another in progressing through the critical final assembly, test, launch, and mission operations. This feature is intended to provide a single individual whose intimate relationship with the spacecraft will permit exact interpretation of spacecraft responses and thus provide a better understanding of the data received from space.

Product Assurance

The responsibility for producing a quality product has long been recognized at both the corporate and division level. This recognition has been underscored by the assignment of the product-assurance function to a vice-president reporting to the division general manager. A comprehensive product-assurance program at every level of the company is in existence. This program has permitted Boeing to achieve a high degree of reliability in its products. A recent study indicated that Minuteman equipment has exceeded the contracted reliability requirements by a ratio of over 4 to 1. Moreover, Minuteman electronics (largely supplied by Boeing and its Voyager team member, Autonetics), has proven to be three orders of magnitude better than MIL-quality state-of-the-art avionic equipment.

To provide strongest product control and maximize the probability of complete Voyager mission success, a product-assurance function reporting directly to the Voyager program manager has been established. This function will encompass and integrate all product-assurance activities, including quality assurance, configuration management and control, and reliability and safety.

Planetary Quarantine

Effective measures to support the international agreement on planetary quarantine have been studied and implemented by a planetary quarantine function reporting directly to the program manager. The authority of this manager will cut across the entire program team. The planetary quarantine manager will ensure that the probability Mars is contaminated prior to the calendar year 2021 as a result of any single launch will not be greater than 1 in 10,000. Currently he has developed and assigned probability allocations to the consideration of contamination by Centaur booster impact, capsule canister impact, propulsion-system exhaust products, and ejecta resulting from spacecraft meteoroid impact. These Boeing-developed allocations will be revised upon receipt of allocations specified by JPL. Contamination constraints for each spacecraft flight will be met by biasing the aiming point and by carefully selecting an insertion orbit. Based on analyses of possible contamination, it has been considered prudent to sterilize the orbit-insertion, orbit-trim, and attitude-control systems. He will conduct (or cause to be conducted) analytical work to evaluate all aspects of this problem before specific constraints are imposed on portions of the spacecraft other than propulsion.

MANAGEMENT APPROACH

The Boeing management approach to the Voyager task has been developed with the following objectives.

- To recognize that the total effort — from the pre-Phase IA period through Phase II acquisition — is based on the single-thread philosophy involving iterations by team members of data originally conceived and set forth by JPL as applicable and reference documents for Phase IA. This data, as provided in the Phase IB RFP, will be further refined and expanded during the proposal and Phase IB to produce the final technical data, program plans, and cost data for Phase II.
- To establish an organization for the total Voyager effort that deliberately introduces a larger number of highly qualified personnel during the early phases of the program than would normally be assigned to a study or program-definition effort. This ensures that key personnel required for later phases become well-founded early in the effort and will be capable of providing a smooth management/technical transition from Phase IB to Phase II. This principle of continuity in assignments of key personnel is in consonance with the documentation single-thread approach discussed above. This principle has been used by Boeing over the years and has contributed to the high reliability and long operational life designed into Boeing products.
- To accomplish the total Voyager effort with a team in which each individual has been selected for: (1) his ability to contribute to the technical success of the system-engineering studies, calculation, preliminary design, engineering services, and program planning involved; and (2) his ability to conduct the managerial affairs that will ultimately be involved in the Voyager development program.
- To ensure that the necessary resources are provided to the program manager as required. Only the resources essential to achievement of Voyager objectives will be assigned to the administrative control of the program manager. He will draw on existing organizations for support in other areas as required. Experience has shown that this arrangement: (1) relieves a program manager of a considerable administrative burden and permits him to concern himself more directly with achieving program goals; and (2) results in a more cost-effective use of corporate facilities and manpower.
- To assign the program manager full authority and responsibility for the conduct of his effort, such that he will be the single point of contact in Boeing for JPL, associate contractors, government agencies, and subcontractors.

The decision to commit a team to conduct the Voyager Phase IA, Phase IB, and Phase II was implemented in the following manner.

- First, as indicated above, these phases were looked at as a single task.

- Second, a breakdown was prepared of the principal functional elements required to accomplish this total task. These elements were prepared in the form of a management chart, Figure 2, which ensured that each facet of the planning required for the total task was provided for. The concept for program implementation provides the same management arrangement for Phase IB as for Phase II, but the phasing of major emphasis shifts from system engineering, preliminary design, and program planning during Phase IB to detailed design, development, fabrication, and test during Phase II.
- Third, qualified individuals were selected for key assignments. These selections were based on the individual's capability, and were made without regard to organizational attachments within the division. The best people were selected for each position. Consideration was given to responsibility growth from Phase IB through the Phase II program.

The mode of operation described above was developed over the years and has proved effective.

MISSION ASSURANCE

The management techniques and disciplines that will be employed to ensure meeting the objectives established by JPL for Voyager are based on experience and include the following.

Program Manager's Authority

The program manager will have authority over the voyager team; this includes selection and retention of key personnel, evaluation of individual performance, and the establishment and determination of the size of his work force. He will lead Boeing representatives in contract negotiations with JPL and has the authority to commit his assigned resources for the accomplishment of the Voyager task.

Responsiveness to JPL

The program manager will provide quick response to JPL direction. All communications between JPL and Boeing will be handled through the program manager's office. A Pasadena office will be established by the program manager to ensure effective communications with JPL. During the first 30 days following contract award, the program manager and a cadre of technical personnel will locate in this office to facilitate a sound understanding of JPL's desires and approach to contract implementation. A technically competent assistant program manager with a small staff will remain in Pasadena during the remainder of the program, ensuring positive communications between JPL and Boeing and effective management direction from Boeing to Philco, Electro-Optical Systems, and Autonetics.

Program Interfaces and Effective Communications

A clear understanding of the total Voyager program-management task and the establishment of effective communications channels between JPL, Boeing, subcontractors, and the associate contractors regarding policies, procedures, and practices is critically essential to successful program management. To this end it is mandatory that the interrelationship of all project management activities be clearly identified and that those aspects of each activity that have an interface relationship to the management control of the program, including, costs, schedules, technical requirements, quantities, and configuration, be documented. This control or baseline must be continually updated as the program progresses, must reflect program management, technical, assembly, and test milestones and interrelationships, and must be specifically keyed to the phase of the program in which a decision or an action is required. The iterations that this baseline data will be subjected to during the course of Phases IA, IB, and II, providing the single thread of technical and management continuity necessary for effective program integration and control, is illustrated in Figure 8.

Effective communication between JPL and Boeing can exist only if JPL and Boeing have a common understanding of the program, including objectives, responsibilities, and interrelationships. To ensure that this understanding is achieved, the program manager has developed event logic networks. These networks portray the program as a series of inputs-outputs and significant technical and management events that occur in the specified sequence. Their development and preparation has forced a critical examination of the program from beginning to end. This ensures that all major JPL, Boeing, subcontractor, and associate contractor events and activities, including their interrelationships and interdependencies, are provided for. This network was used for schedule developments presented in Section 5.0 of Volume A. In addition, a series of integrated event logic networks at the subsystem level and at other selected levels of the program breakdown structure were used as the basis for the development of the schedules.

Subcontract Management and Technical Integration

The management of subcontractors is the joint responsibility of the engineering manager and the operations manager. Since the performance of subcontractors will have a direct influence on Boeing's ability to meet program objectives, a closed-loop communication channel between Boeing and the subcontractors will be used to provide visibility to direct, integrate, and control subcontracted efforts effectively. Figure 9 illustrates the closed-loop communication channel.

Primary responsibility for technical management of subcontract programs is assigned to the Boeing subsystem engineer whose system employs the subcontracted article. A technical person assigned this responsibility is selected on the basis of his technical competence in the area assigned and his ability to

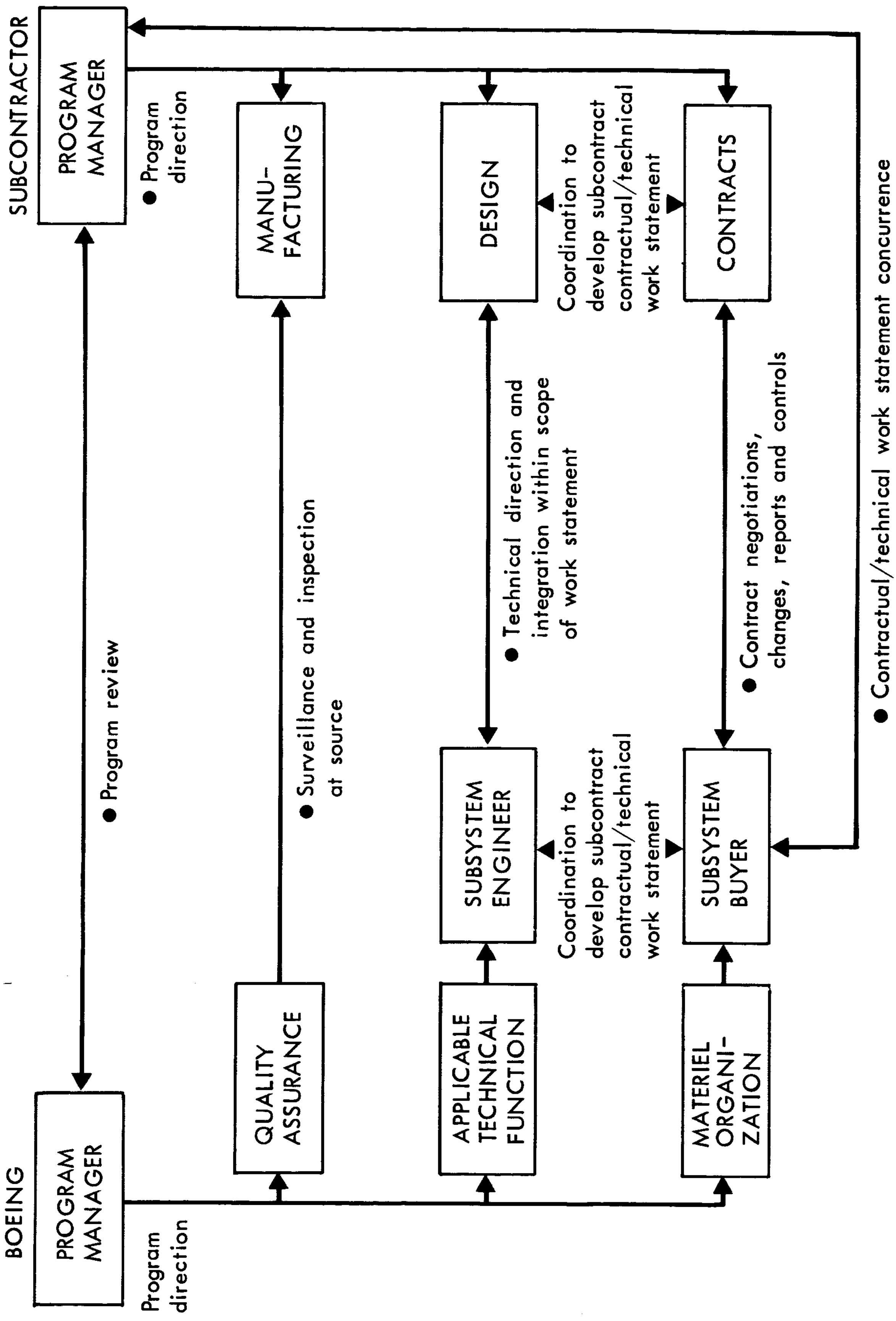
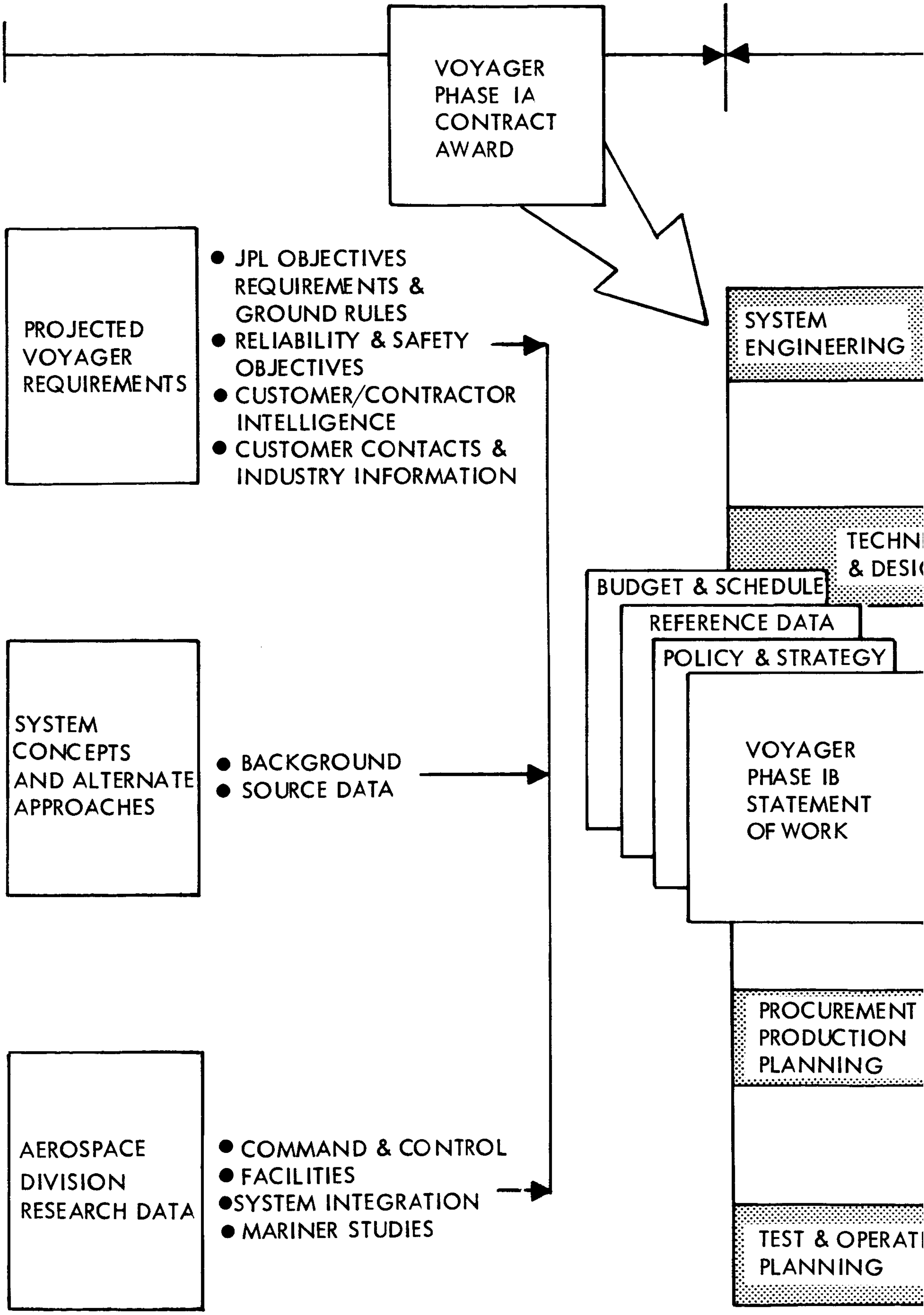


Figure 9: Boeing/Subcontractor Closed Loop Communication Channel


VOYAGER PHASE IA CONTRACT AWARD
PROJECTED VOYAGER REQUIREMENTS
● JPL OBJECTIVES REQUIREMENTS & GROUND RULES
● RELIABILITY & SAFETY OBJECTIVES
● CUSTOMER/CONTRACTOR INTELLIGENCE
● CUSTOMER CONTACTS & INDUSTRY INFORMATION
SYSTEM ENGINEERING
TECHN
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BUDGET & SCHEDULE
REFERENCE DATA
POLICY & STRATEGY
VOYAGER PHASE IB STATEMENT OF WORK
SYSTEM CONCEPTS AND ALTERNATE APPROACHES
● BACKGROUND
● SOURCE DATA
PROCUREMENT PRODUCTION PLANNING
AEROSPACE DIVISION RESEARCH DATA
● COMMAND & CONTROL
● FACILITIES
●SYSTEM INTEGRATION
● MARINER STUDIES
TEST & OPERAT
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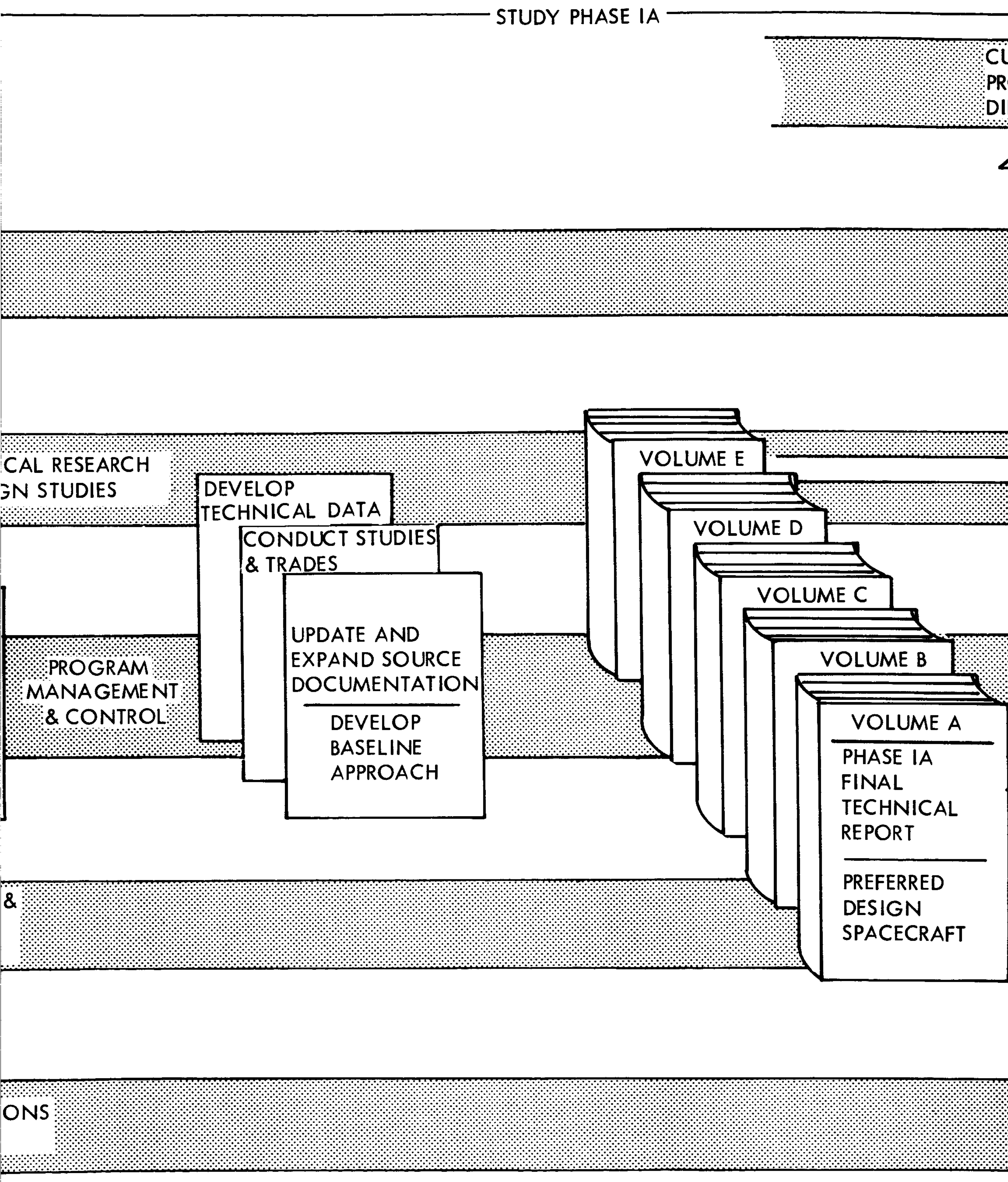
STUDY PHASE IA
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GN STUDIES
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CONDUCT STUDIES & TRADES
UPDATE AND EXPAND SOURCE DOCUMENTATION
DEVELOP BASELINE APPROACH
PROGRAM MANAGEMENT & CONTROL
VOLUME E
VOLUME D
VOLUME C
VOLUME B
VOLUME A
PHASE IA FINAL TECHNICAL REPORT
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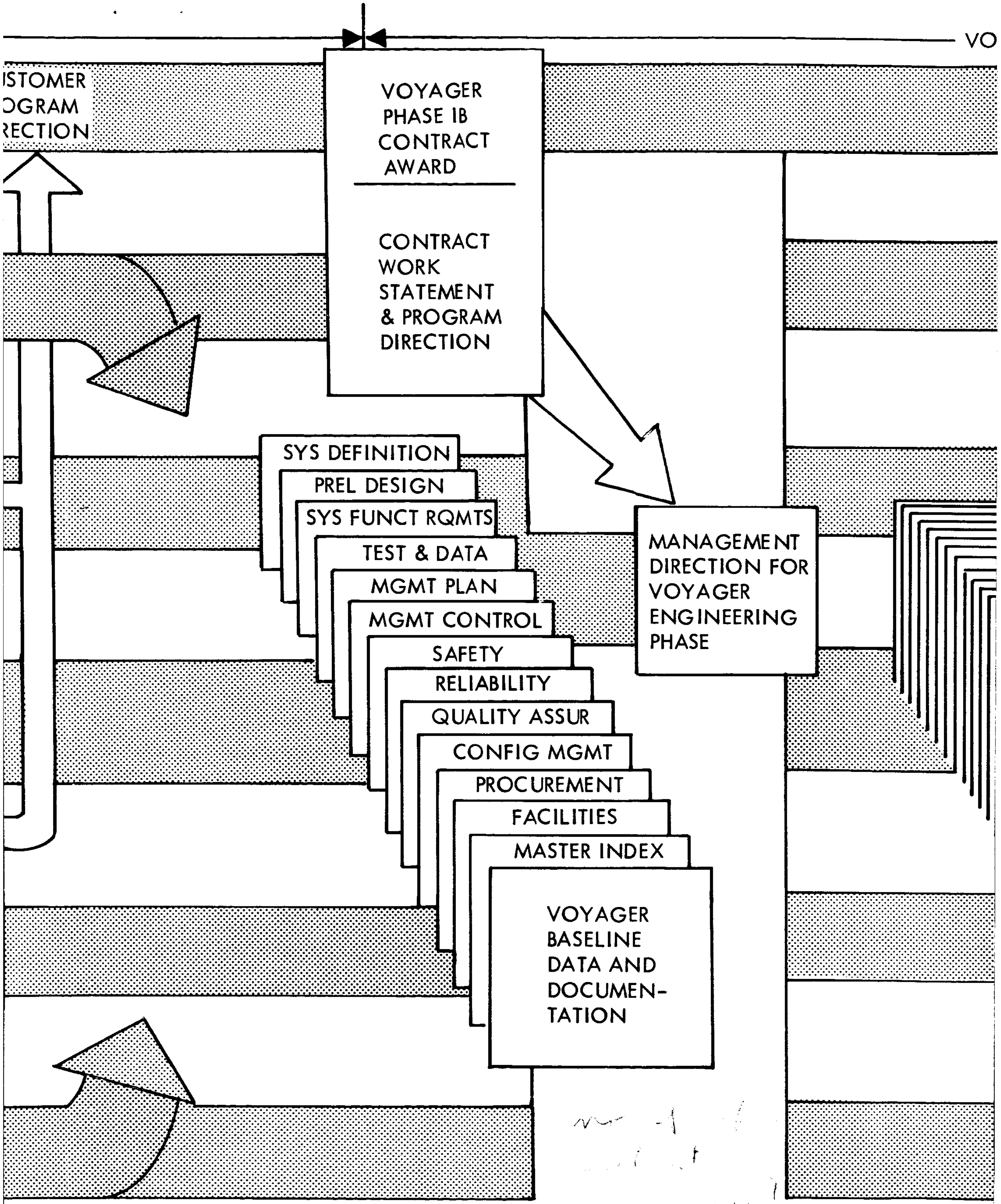

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SYS FUNCT RQMTS
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MGMT CONTROL
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RELIABILITY
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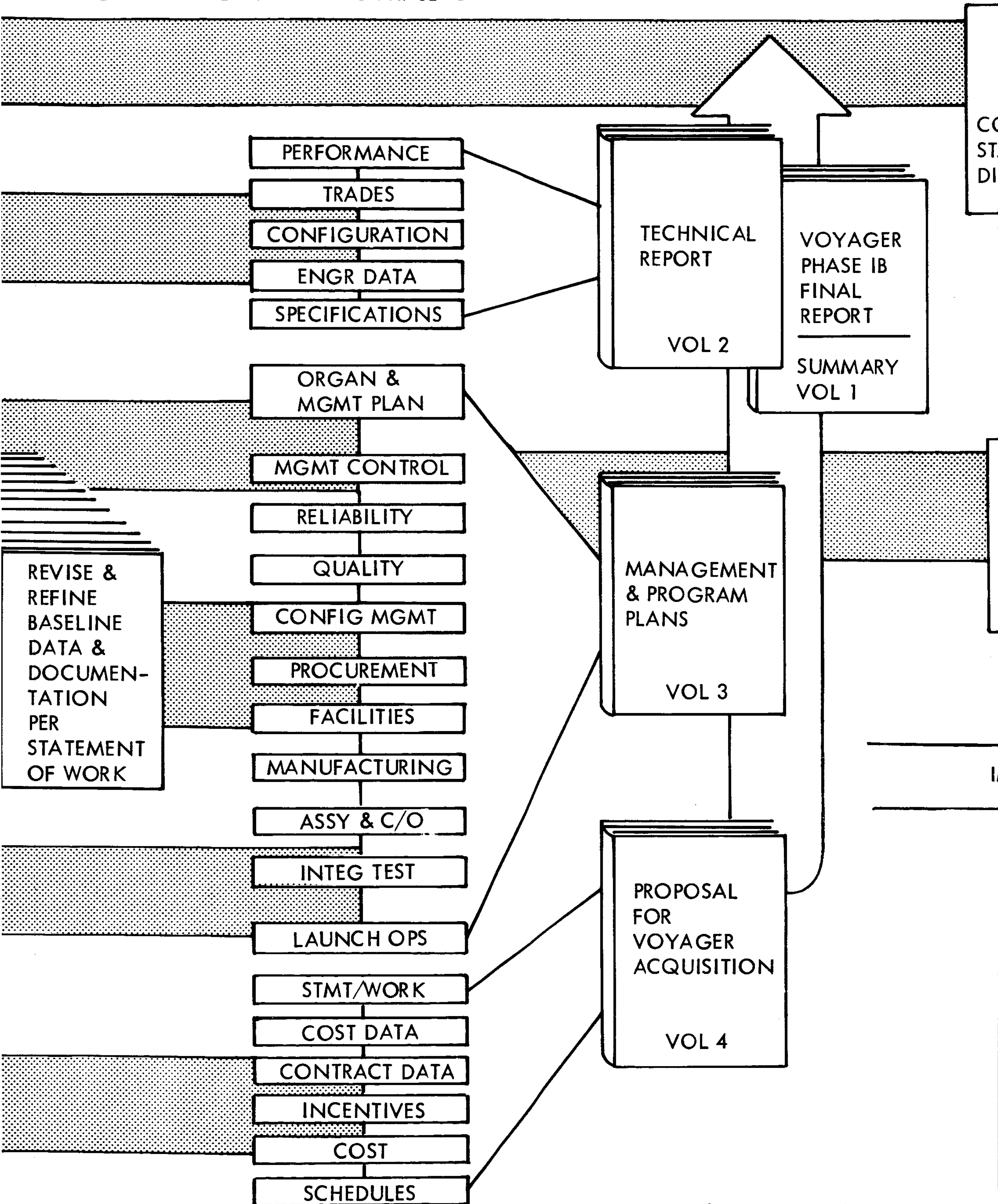
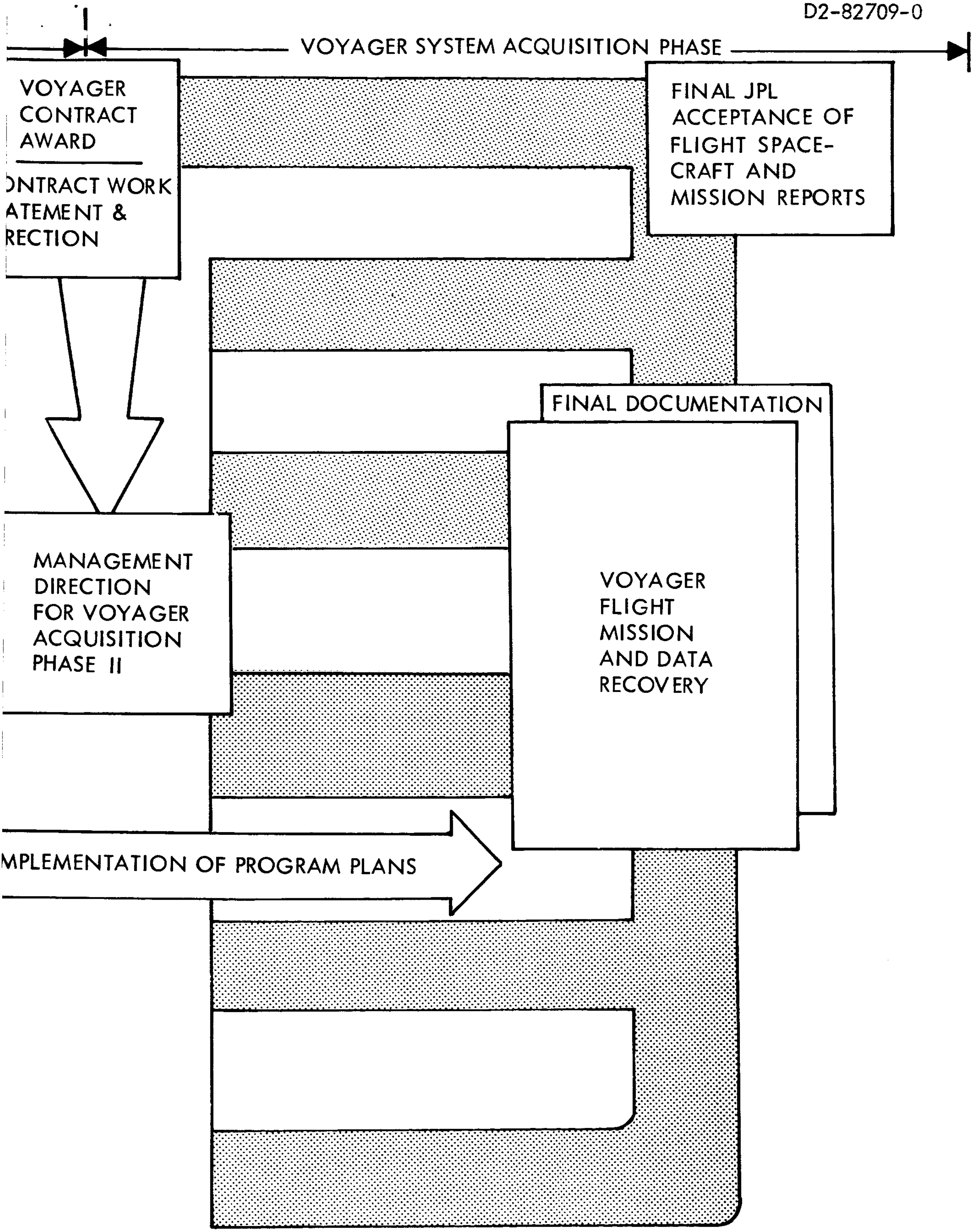


Figure 8: Single Thread (



5

Concept — Continuity of Technical and Management Data manage and direct the technical integration task. He will ensure technical integration of the subcontractor's effort into Boeing's effort by: (1) developing the technical work statement; (2) approving the contractual work statement and schedules; (3) continually monitoring subcontractor technical status and progress; (4) providing the subcontractor with all data that has any potential effect on his effort; and (5) keeping subcontractors informed of the total task and progress.

A subcontract administrator assigned as buyer will be responsible for the development of the contractual work statement, costs, negotiations, and administration and contractual control of the subcontract. He will ensure that the subcontractor is continually advised of program requirement changes through appropriate channels. Formal subcontract administration and control will be supported by periodic reporting in the following areas: technical progress, cost status, and manpower expenditure and forecast (standard and overtime). Reporting formats will be compatible with those of Boeing to JPL. Additionally product assurance through resident representatives or random visits will maintain surveillance over the subcontractor's fabrication, assembly, and test activities. In addition to the above program and technical management at the working level, the subcontract administrator will work closely with the subcontractor program manager to maintain continual concurrence between Boeing and the subcontractor on the statement of work. Periodic reviews will be conducted between the Boeing program manager and the subcontractor program manager.

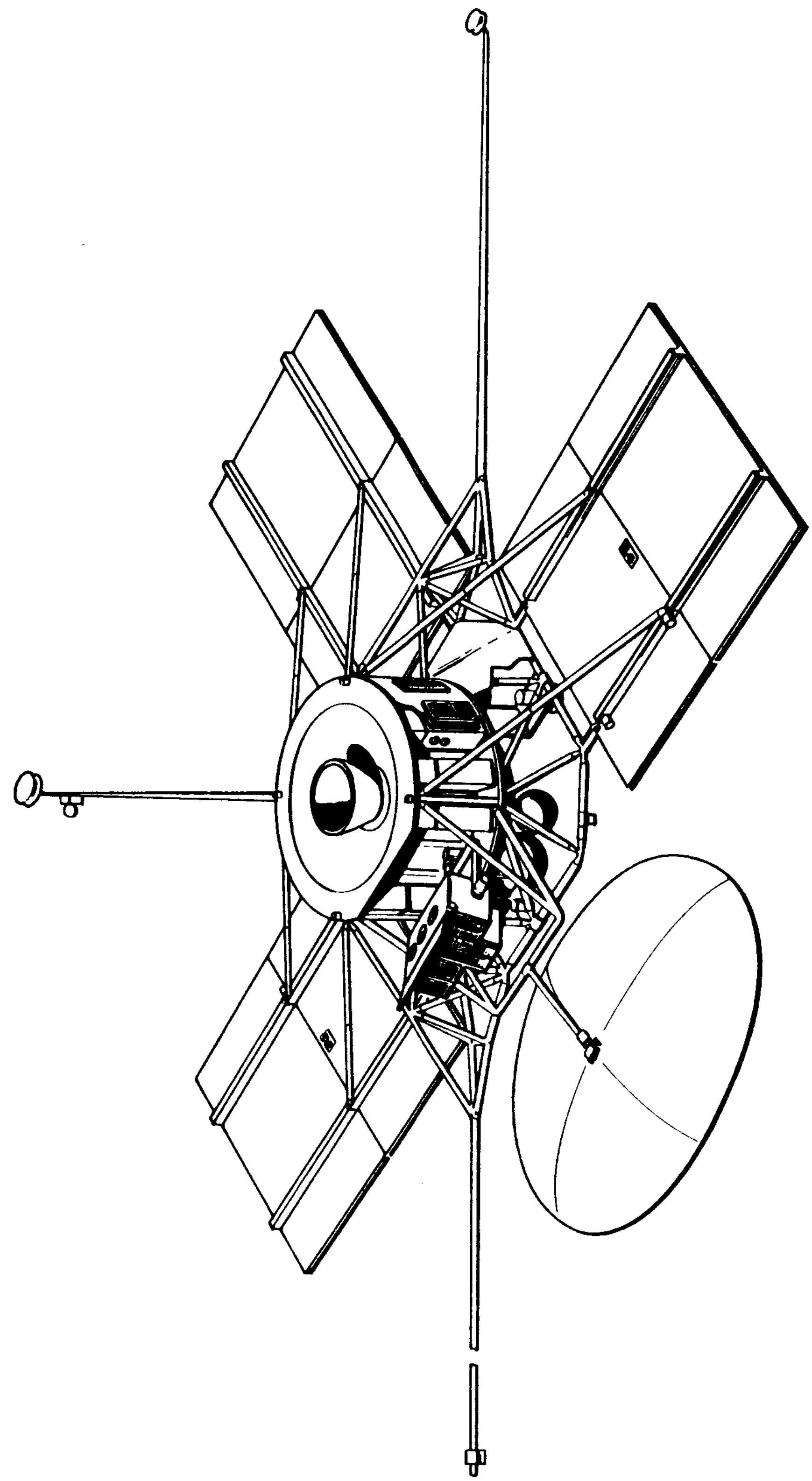


Figure 10: Voyager Flight Spacecraft — Preferred Design

TECHNICAL HIGHLIGHTS

The Boeing-preferred Flight Spacecraft concept has evolved from an ordered sequence of preliminary design events. Parametric studies were made for all subsystems, based on the JPL mission specifications and guidelines and through use of Mariner C, Ranger, and Lunar Orbiter information. These, in context with mission functional sequences, established the boundaries or discrete points of the operating characteristics maximation as a function of reliability, cost, weight, power required, volumes, etc. Subsystem concepts chosen as a result of these trade studies were incorporated into the system. The system was then optimized considering the same parameters noted above, with due regard for subsystem interaction as well as operational support equipment, spacecraft Science Payload estimates, test requirements, and the varied NASA system and operational elements with which Voyager will interface.

PREFERRED FLIGHT SPACECRAFT

The Boeing design approach has emphasized reliability, versatility, and program flexibility. The long times inherent in the Mars mission demand high reliability; hence, the spacecraft design is practical and conservative, with redundancy in all key systems. The nation's substantial investment in the hardware to perform the Mars missions dictates maximum utility; hence, the Boeing spacecraft has been designed for use on either of two different launch vehicles and is sized to achieve a range of flight trajectories and Mars orbits between 1969 and 1977, inclusive.

The preferred spacecraft design is shown in Figure 10. The structure includes a simple truss base, 10 feet wide at the bottom and 5 feet wide at the top, constructed of welded 6Al-4V titanium tubing. This truss base attaches to the Centaur adapter and supports the antennas, solar panels, and the magnetometer boom. The equipment modular packages are attached to a 5-foot-diameter cylindrical magnesium shell mounted on top of the truss base. The Flight Capsule is supported by an adapter ring, with loads carried through the cylindrical shell by four columns.

Stowed aboard the booster, the spacecraft is 57 inches high and fits within the specified Centaur shroud envelope. With the solar panels deployed in the flight configuration, the spacecraft is 30 feet wide from solar-panel tip to solar-panel tip. The magnetometer boom extends 31 feet and the antenna booms are 17 and 18 feet, respectively, for the VHF and omnidirectional systems. The 20 equipment modules, mounted on the central magnesium shell, are thermally controlled by radiation from the louvered external faces of the individual packages.

The high reliability characteristics of the spacecraft design were achieved by selecting space-proven components and parts where possible, and through the use of redundancy in the critical system elements. Where selection of non-space-proven items was necessary to meet the design ground rules, careful

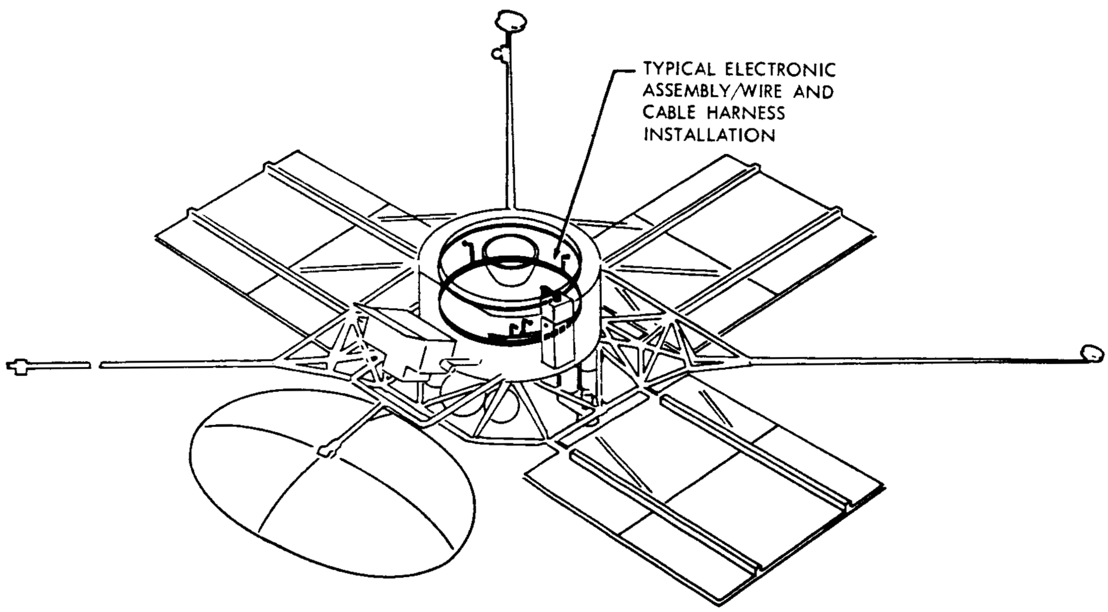


Figure 11: Voyager Flight Spacecraft — Modular Packaging

evaluations were made to ensure that the selected elements could be fully developed prior to the design freeze date of July 1966.

Allocations of reliability were made for each of the subsystems, the OSE, the launch vehicle, the performance factors, and to the meteoroid-damage hazards, based on the specified probability of success for various mission functions within the primary objective, as stated in the JPL "Preliminary Voyager 1971 Mission Specifications." Assessment of the preferred design has indicated that — in each case — the allocation was met or exceeded, giving a total probability of success for the performance of orbital operations of 47.35 percent (rather than the specified 45 percent) as shown in Table 1. It should be noted that the reliability assessment for the Science Payload was assumed to be 0.6726. If the government-furnished Science Payload can be designed up to give higher reliability, the 47.35 percent probability of success of orbital operations can be raised proportionately.

The Boeing-preferred Flight Spacecraft design has resulted in total system weight of 4965 pounds, which is well within the specification weight of 5250 pounds (excluding 250 pounds for the Science Payload). The 285-pound contingency is available for selective use during the design detail phase. The Spacecraft Bus weight is 1565 pounds with contingency of 185 pounds; the Propulsion Module weight is 3400 pounds with contingency of 100 pounds. Table 2 is a weight summary of the various elements of the Flight Spacecraft.

Modular Packaging

Components of the spacecraft as well as subassemblies have been arranged and packaged for convenient access (see Figure 11). This results in greater ease of installation, maintenance, and testing, thereby enhancing the reliability of the spacecraft. The electrical, thermal, and mechanical elements have been made relatively independent so as to minimize physical interfaces as well as those of management. In addition, these relatively independent subsystems afford great schedule and test flexibility. If a subsystem experiences difficulties and does not meet its schedule, its impact on the other spacecraft subsystems is minimized. This should lead to greater visibility of subcontractor and team performance as well as protecting the unalterable launch opportunity. The electronic packages are located to balance the Flight Spacecraft for proper center of gravity. The electronic packages generating the most heat are separated and located near equipment generating the least heat. Electronic packages are also located to minimize the distance between interconnecting packages. Equipment with related functions are packaged together to eliminate interconnecting cabling.

Telecommunications

The Voyager telecommunications system (Figure 12) is designed to return to Earth the maximum possible amount of scientific data within the constraints of vehicle size and weight, and subsystem performance and reliability. The com-

Table 1: PREFERRED SYSTEM RELIABILITY SUMMARY

System Element	Reliability Allocation	Reliability Assessed
Spacecraft		
Spacecraft Bus		
Telecommunications	0.841	0.8416
Attitude Reference	0.996	0.9969
Autopilot	0.999	0.9998
Reaction Control	0.999	0.9996
CC&S	0.994	0.9945
Electrical Power	0.992	0.9923
Propulsion	0.996	0.9968
Structure and Cabling	0.999	0.9999
Mechanisms	0.999	0.9988
Temperature Control	0.996	0.9960
Pyrotechnics	*	*
Spacecraft Bus (Subtotal)	0.817	0.8201
Science Payload	0.650‡	0.6726‡
Spacecraft (Subtotal)	0.531	0.5516
OSE	0.970	0.970
Launch Vehicle	0.900	0.900
Performance Factors		
Midcourse	0.997	0.997
Orbit Insertion	0.997	0.997
Orbit Trim	0.999	0.999
No Meteoroid Damage	0.990	0.990
Contingency	0.987	---
Total	0.450	0.4735

* Included for reliability in CC&S

‡ For all planetary experiments

Table 2: PREFERRED SYSTEM WEIGHT SUMMARY

System Element	Weight (pounds)		
Flight Spacecraft	Allocated		Actual
Spacecraft Bus	1750		
Telecommunications		207	
Attitude Reference		51	
Autopilot		11	
Reaction Control		212	
CC &S		58	
Electrical Power		457	
Structure		374	
Mechanisms		59	
Temperature Control		36	
Cabling		100	
Contingency			185
Spacecraft Bus (subtotal)		(1565)	1750
Propulsion	3500		
Midcourse		508	
Orbit Insertion		2686	
Structures and Cabling		135	
Temperature Control		71	
Contingency			100
Propulsion (subtotal)		(3400)	3500
Science Payload	250	250	
Flight Spacecraft (total)	5500	(5214)	5500

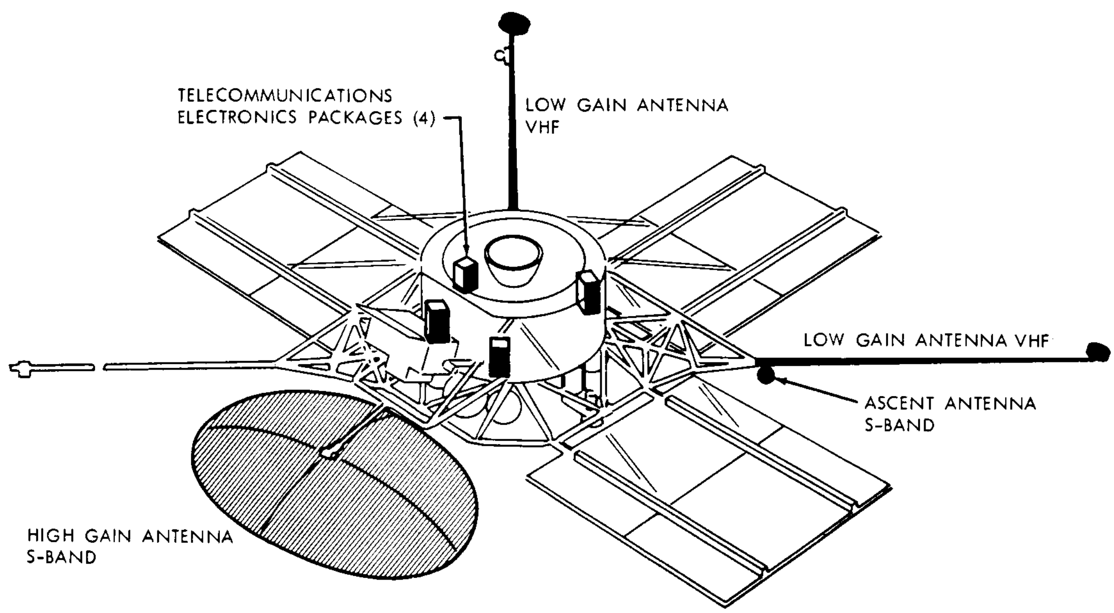


Figure 12: Voyager Flight Spacecraft — Telecommunications

munication system selected for Voyager is a fully redundant, conventional, S-band system using a 50-watt traveling-wave tube (TWT) and an 8-foot by 12-foot paraboloidal high-gain antenna. This, coupled with the 210-foot ground antenna, allows real-time transmission of high-rate scientific data (48,000 bits per second) for approximately 2 months after encounter in the nominal case.

Two tape recorders allow storage of 2×10^8 bits for those periods when Earth transmission is prevented by occultation, or when link margins will not support high-rate transmission. Exceptional system versatility is supplied by the wide variety of operational modes available. See Table 3 for a summary of the telemetry modes.

A low-noise tunnel-diode preamplifier in the radio subsystem allows reception of ground commands through the omnidirectional low-gain antenna for up to 2 months after encounter, thus allowing for corrective action when the link through the high-gain antenna is not operational.

Major elements of the system and their functional interrelations are illustrated in Figure 13. The design features that provide a significant improvement in performance over current deep-space systems are described below.

<u>A 50-Watt Power Amplifier</u> — Traveling-wave-tube amplifiers operating at this power level can be through the engineering protostage by July 1966. The TWT has been selected for Voyager because of its advanced development and history of reliable performance.

<u>An 8-Foot by 12-Foot Paraboloidal High-Gain Antenna Providing 34.3-Decibel Gain</u> — This antenna is the maximum size, rigid, nonsegmented antenna that will fit within the vehicle shroud and be compatible with the Boeing-designed spacecraft. This antenna is gimbaled about two axes and pointed to an accuracy of ±0.6-degree total error in each axis to minimize pointing losses. Careful study of servo design, installation, and vehicle attitude stabilization indicates that this accuracy can be achieved.

<u>Biorthogonal Block Coding of the Digital Data Stream</u> — A 16,5 code provides the equivalent of 2 decibels in link gain without degrading the specified bit error rate ($p_e^b = 5 \times 10^{-3}$).

The combination of the above features, together with use of the 210-foot receiving antennas being developed for the deep-space stations, results in a system that can provide <u>a 48,000-bit-per-second data rate at Mars encounter.</u> This corresponds to transmission of one 400-line by 400-line television picture every 20 seconds. Assuming an encounter date of December 23, 1971, a positive margin will exist at this data rate for encounter plus 73 days under nominal performance and for encounter plus 10 days at worst-case conditions.

To illustrate the effectiveness of the real-time and high-rate stored data modes, the number of television pictures returned to Earth versus time in orbit is

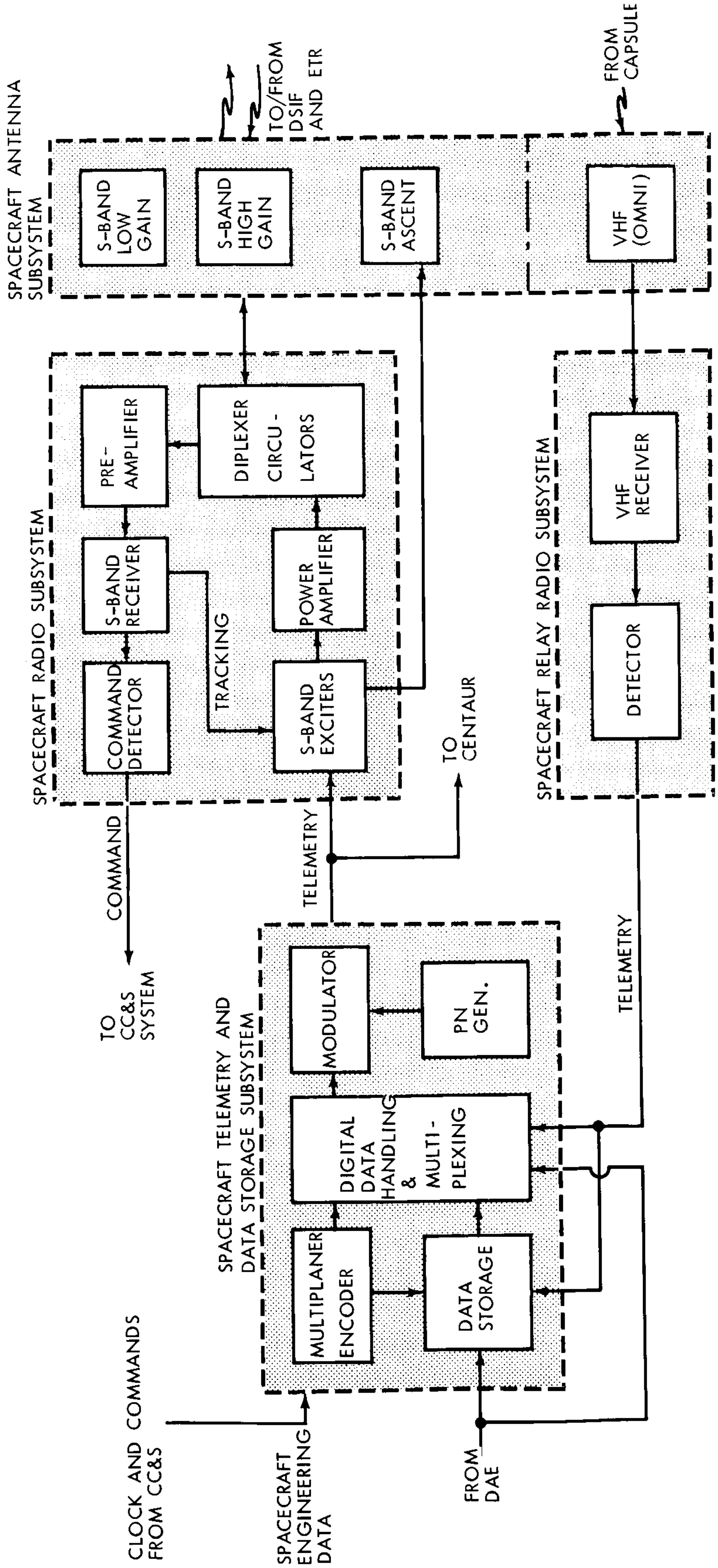


Figure 13: Spacecraft Telecommunication Functional Grouping

Table 3: TELEMETRY MODES

Mode	Data Type	Bit Rate	Modulation	Subcarrier Frequency, Lower Data Channel	Subcarrier Frequency, Upper Data Channel	Mission Phases
1	Engineering Capsule	11-1/9 11-1/9 } 22-2/9	Two-Channel Coherent PSK/PM	Data 400 cps Sync 200 cps		Launch Acquisition Maneuver
2	Engineering Capsule Cruise Science	11-1/9 11-1/9 111-1/9 } 133-1/3	Coherent PSK/PM	533-1/3 cps		Cruise
3	Engineering Capsule Stored Engineering	11-1/9 11-1/9 111-1/9 } 133-1/3	Coherent PSK/PM	533-1/3 cps		Post-maneuver Option
4	Engineering	5-5/9	Two-Channel Coherent PSK/PM	Data 100 cps Sync 50 cps		Emergency Cruise or Encounter
5A	Engineering Cruise Science Capsule Planetary	66-2/3 166-2/3 166-2/3 } 400 8000	Coherent PSK/PM Lower Coded PSK/PM Upper	1.6 kc	102.4 kc	Encounter and Early Orbital
5B	Engineering Cruise Science Capsule Planetary	66-2/3 166-2/3 166-2/3 } 400 4000	Coherent PSK/PM Lower Coded PSK/PM Upper	1.6 kc	102.4 kc	Optional Mid-orbital
5C	Engineering Cruise Science Capsule Planetary Science	66-2/3 166-2/3 166-2/3 } 400 2000	Coherent PSK/PM Lower Coded PSK/PM Upper	1.6 kc	102.4 kc	Optional Late Orbital
6	Engineering Cruise Science Capsule Planetary Science	66-2/3 166-2/3 166-2/3 } 400 48,000	Coherent PSK/PM Lower Coded PSK/PM Upper	9.6 kc	614.4 kc	Optional Encounter and Orbital

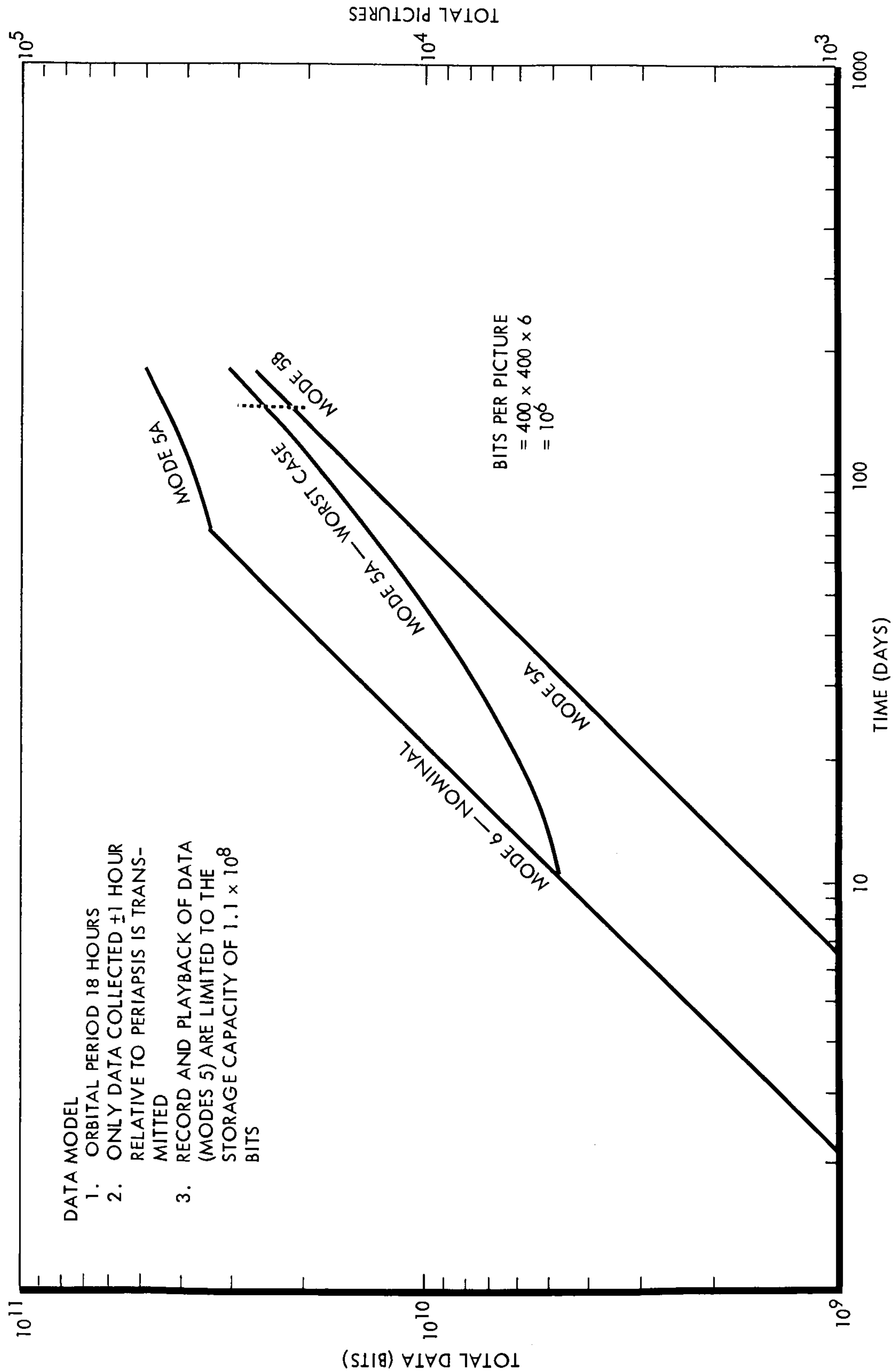


Figure 14: Total Information Bits Versus Mission Time

plotted as a function of link margins in Figure 14. Of particular significance is the fact that, if nominal conditions prevail, 49,000 pictures have been transmitted at the end of 6 months. Under worst-case conditions, 26,000 pictures are still obtained without interference to the transmission of other scientific data (including capsule) and engineering data at the rates specified in Table 3.

Central Computer and Sequencer

The central computer and sequencer (CC&S) shown in Figure 15 is designed to provide event timing, sequencing, synchronization, and switching signals for spacecraft control and operation during prelaunch and all mission operations. To meet these requirements, the CC&S incorporates both data-processing and power-switching circuitry. The design selected utilizes a modified NASA Lunar Orbiter programmer, which is a special-purpose, memory-oriented (digital) computer. The equipment consists of two separate functional assemblies: the control assembly containing redundant data processors and the switching assembly providing complete redundancy in all power switching.

The control assembly is designed to provide the timing and command issuance, sequencing, and storage for all functions required to perform event control of the spacecraft. This component also provides low-level interfacing with other spacecraft subsystems.

The CC&S switching assembly is developed to provide power-switching signals requiring high voltage and current outputs. Power switching is required for firing squibs, solenoid drivers, motor drivers, and relay drivers. Low-level signals originating in the control assembly cause the appropriate power-switching signal to be issued from the switching assembly to the specific subsystem.

The random-access magnetic-core memories within the control assembly provide storage of a preplanned sequence of spacecraft events for directing the mission, and accept changes to that sequence at any time as commanded by Mission Operations. The number and complexity of Earth-based commands have been minimized by the CC&S design so only mission variables are transmitted to the spacecraft during normal operations. The design provides capability to execute up to 332 different commands and has a memory capacity of 256 words at 21 bits per word. Up to 13 different discrete command signals can be simultaneously issued with a single command word, thus providing flexibility while reducing the storage requirements. Repetitive use of subroutines and indexing of particular command functions help minimize storage requirements.

The CC&S logic has been developed to minimize ground commands and internal storage. The unit functions by storing preset operational routines. These routines are sequenced by both ground commands and stored commands. Repetitive sequencing by stored commands is accomplished by address modifications. Constant values employed for magnitude comparison are sequentially stored in blocks of addresses so that the repetitive main routing can obtain the proper constants for each maneuver. Any stored word can be modified by inserting new words transmitted during flight. Command words sent from the ground are first double parity-checked and then either stored in the memory or executed immediately (real-time use). They will also be telemetered for ground verification.

The CC&S is the focus for functional control and interfaces within the spacecraft. The interface functions between the CC&S and the spacecraft subsystems are shown in Figure 16.

The NASA Lunar Orbiter programmer is directly applicable to the Voyager CC&S. The development status of this programmer is that it has completed development testing and is currently undergoing reliability testing. It has successfully completed 3 months of thermal vacuum and vibration testing. The system will be space-qualified by July 1966.

The choice of the CC&S design is particularly significant since the Voyager "prototype" will have accumulated many hours of running time, as well as a head start on reliability testing and an understanding of possible failure modes as a result of the current Lunar Orbiter program.

Attitude Reference and Autopilot

The attitude reference and autopilot subsystem (Figure 17) provides input signals to the reactor-control thruster valves, to the jet vane actuators of the midcourse engines, and to the secondary injection valves of the orbit-insertion engine such that the spacecraft attitude, attitude rate, thrust-vector alignment, and velocity are controlled within specified limits. The subsystem depends on the central computer and sequencer for commands, integration, comparison, and switching.

This proposed subsystem is comprised of celestial reference sensors, an inertial reference unit, and an autopilot that controls both powered and unpowered flight. Celestial reference sensors are space-proven instruments. Two fully redundant Barnes/JPL Canopus trackers used on Mariner IV are applied. The Nortronics Sun sensor chosen for Mariner IV is used with a Ball Brothers Sun sensor as backup. The Ball Brothers Sun sensor has been space-proven in the Orbiting Astronomical Observatory program. The choice of the Ball Brothers unit for backup was made to minimize the effects of identical failure modes of identical equipment. The inertial reference unit provides redundant accelerometers and strapdown gyros. The Autonetics free-rotor G-10B gyros were selected for Voyager.

The primary accelerometer chosen for Voyager is the space-proven Bell DVM IIIB. The Autonetics Electromagnetic Miniature Accelerometer (EMA) was selected as a redundant unit because of its potentially great reliability, small weight and power, and to avoid use of identical primary and backup units. The two accelerometers are aligned with the thrust axis, and are operated in parallel to measure ΔV. The autopilot is basically an analog device with d.c. amplifiers. It can be switched to operate with the various sensors in rate or limit cycle modes to drive the spacecraft attitude thrusters and propulsion-engine thrust-vector controls.

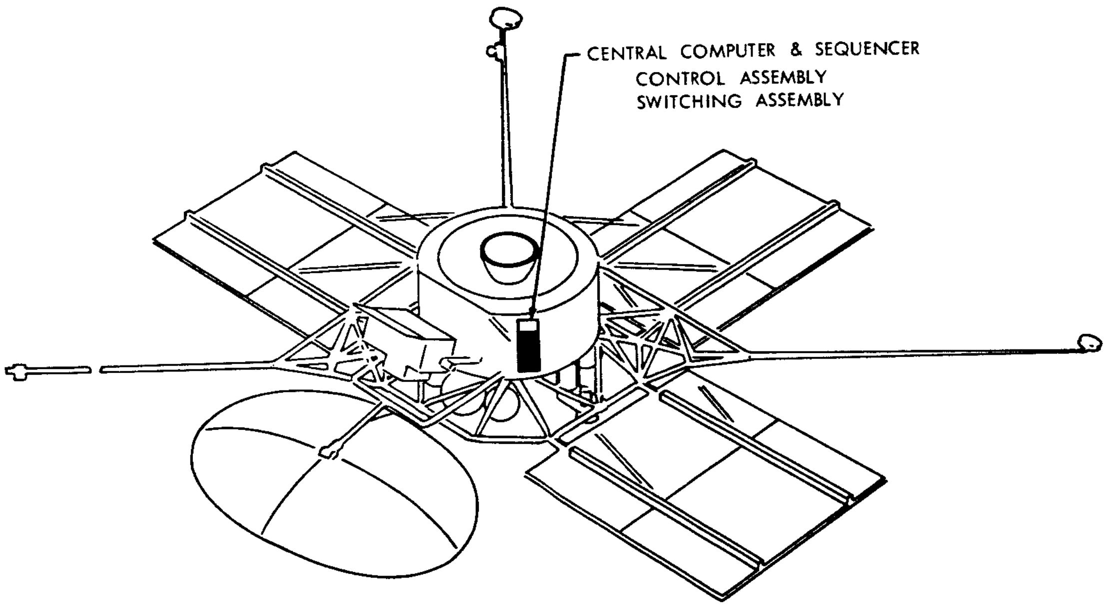


Figure 15: Voyager Flight Spacecraft — CC&S

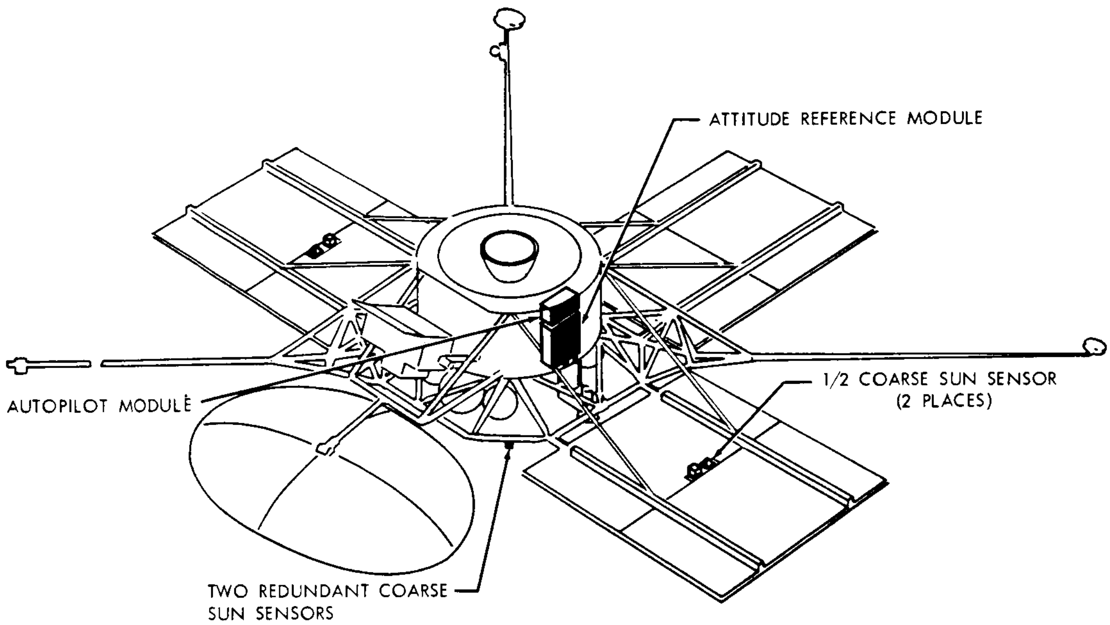
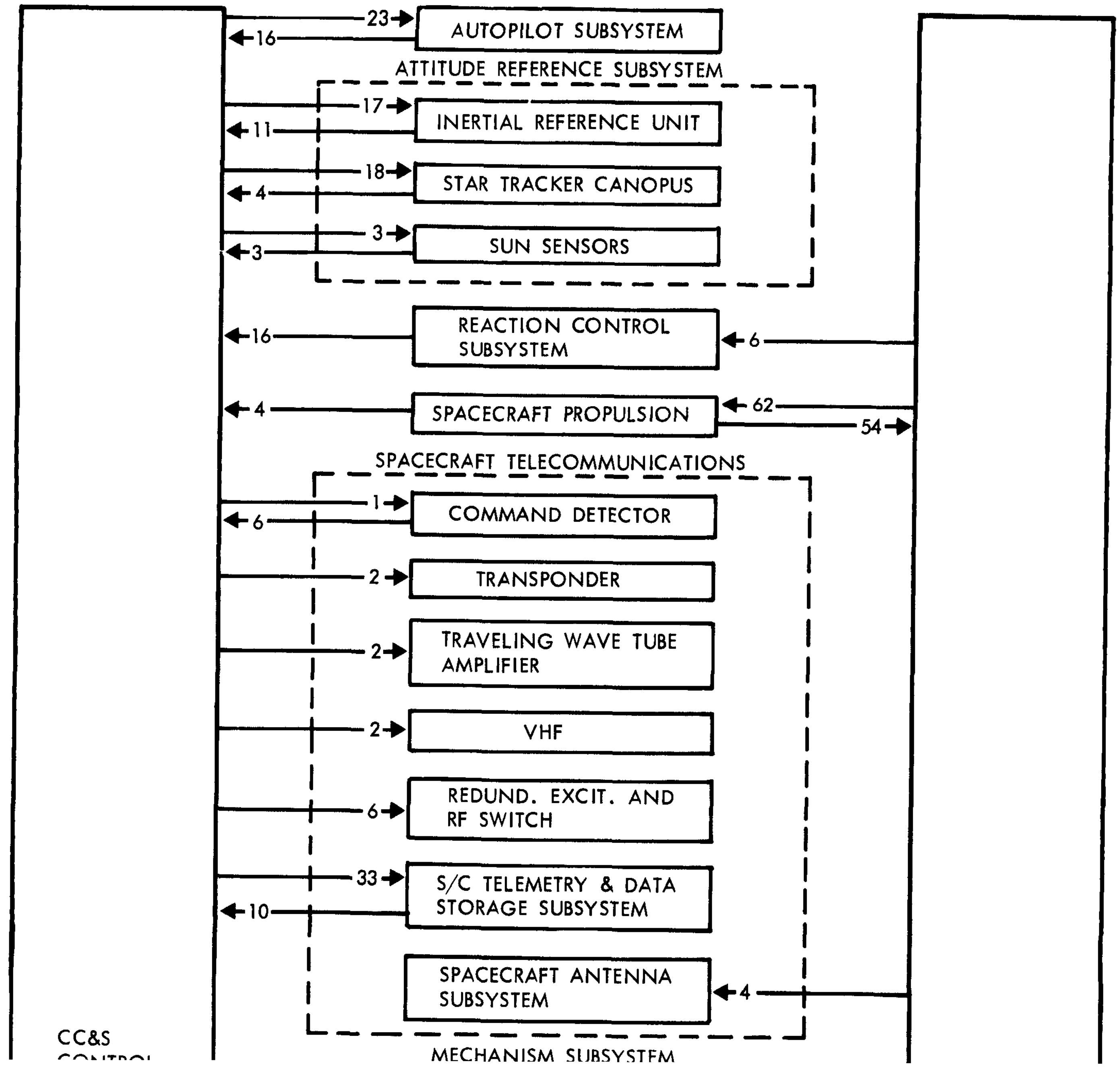
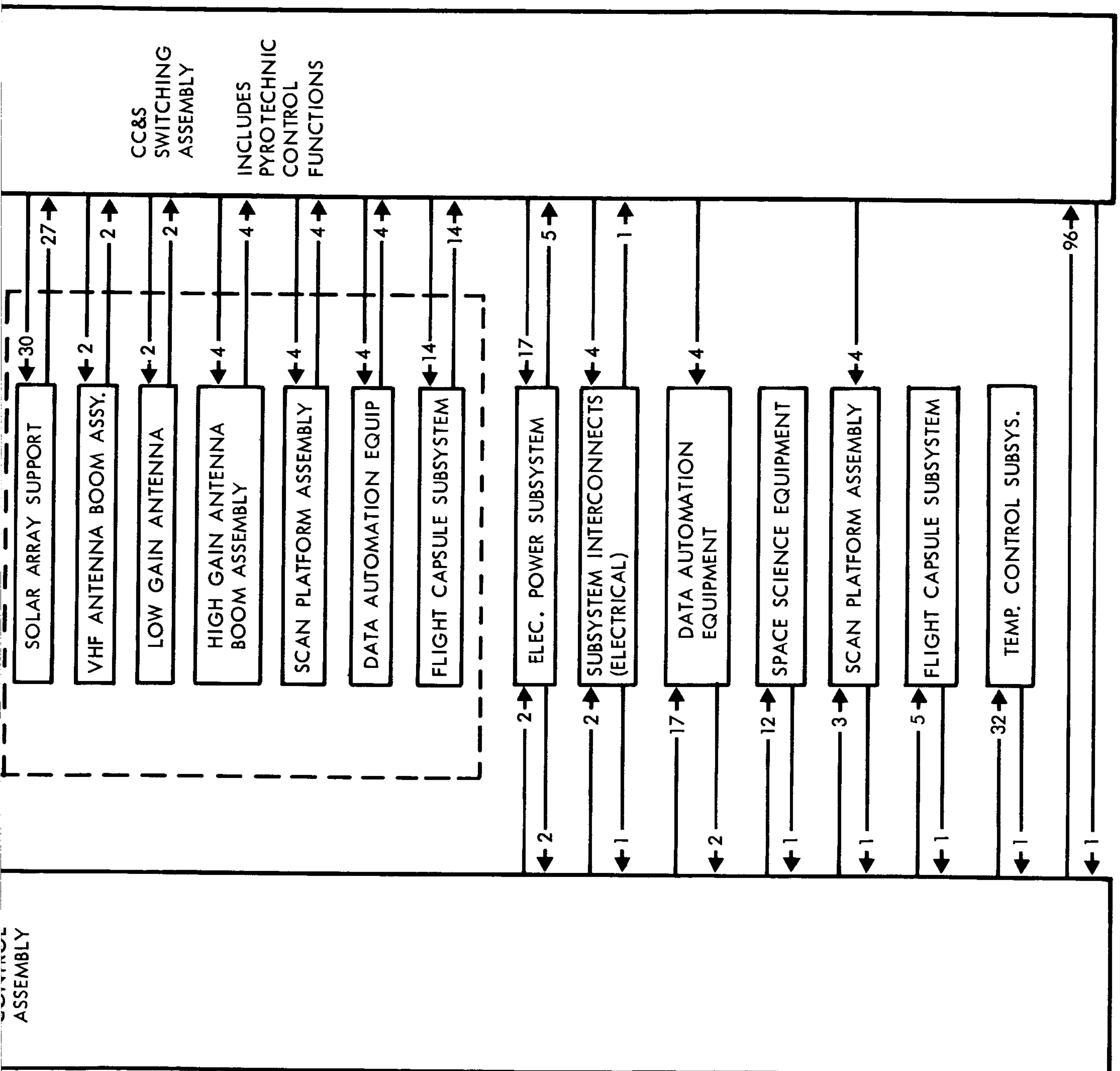


Figure 17: Voyager Flight Spacecraft — Attitude Reference and Autopilot



AUTOPILOT SUBSYSTEM
23
16
ATTITUDE REFERENCE SUBSYSTEM
INERTIAL REFERENCE UNIT
17
11
STAR TRACKER CANOPUS
18
4
SUN SENSORS
3
3
REACTION CONTROL SUBSYSTEM
16
6
SPACECRAFT PROPULSION
4
62
54
SPACECRAFT TELECOMMUNICATIONS
COMMAND DETECTOR
1
6
TRANSPONDER
2
TRAVELING WAVE TUBE AMPLIFIER
2
VHF
2
REDUND. EXCIT. AND RF SWITCH
6
S/C TELEMETRY & DATA STORAGE SUBSYSTEM
33
10
SPACECRAFT ANTENNA SUBSYSTEM
4
CC&S
MECHANISM SUBSYSTEM



For further information see Figure 4.8-14 and 4.8-15.

Figure 16: CC & S — Spacecraft Subsystems Interface Block Diagram

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The location of the attitude reference and autopilot subsystem equipment, including the Sun sensor assemblies, is shown in Figure 17. A brief description of each of the major components is given below.

The inertial-reference-unit gyros are used to maintain attitude when data from optical sensors is not available (i.e., during occultation and maneuvers). The G-10B gyros were chosen because of the superior reliability exhibited by the basic Autonetics two-axis, free-rotor gyro design during more than 17,000,000 hours of Minuteman operational experience. The G-10B gyro is a scaled version of the Minuteman G-6B4 gyro and has an estimated MTBF of more than 1,000,000 hours. The low-weight G-10B gyro has low power requirements and no wearout mechanisms.

The inertial-reference-unit accelerometers are used to sense acceleration during midcourse and orbit-insertion velocity corrections. Output of the accelerometers is integrated in the central computer and sequencer to measure velocity change. For midcourse corrections, ΔV thus measured is compared to commanded value, and acts to terminate thrust when the desired value is achieved. During the orbit-insertion acceleration, the accelerometers provide engineering data for eventual transmittal to the DSIF. The primary accelerometer, Bell DVM-IIIB, is a developed production instrument and has been fully qualified, flight-proof tested, and delivered for use on the Scout vehicle, Minuteman reentry vehicle, and the NASA SERT program. The sensor portion has been used on the Vega, Ranger, Mariner, and other programs. Development of the Autonetics EMA accelerometer was initiated 2.5 years ago and is presently planned to be part of a piggyback satellite payload in early 1966.

The Canopus sensor provides roll reference data during cruise. The JPL-Barnes sensor was selected as both primary and redundant unit; this is a space-proven component with prior usage on the Mariner.

The Sun sensors provide the pitch and yaw information used to orient the roll axis and solar cells toward the Sun. Two basic types of detectors, silicon and cadmium sulfide, were considered. Silicon-cell output is a function of light intensity, which causes a change in loop gain as the spacecraft moves away from the Sun towards Mars. Compensation for this gain change requires a minor increase in system complexity. The output from cadmium-sulfide cells will not exhibit this loop gain change. Ball Brothers silicon and Nortronics cadmium-sulfide sensors have operated with no failure on OAO, Mariner, and other programs. Both were selected for use on the preferred systems to provide dissimilar redundancy.

The autopilot operates in various modes as commanded by the CC&S to provide signals for attitude control of the spacecraft. Major divisions within the autopilot are computation and logic circuitry and actuator driver circuits. Mechanization is all analog with derived rate stabilization during limit cycle operation. The attitude reference and autopilot subsystem is a conservative design utilizing

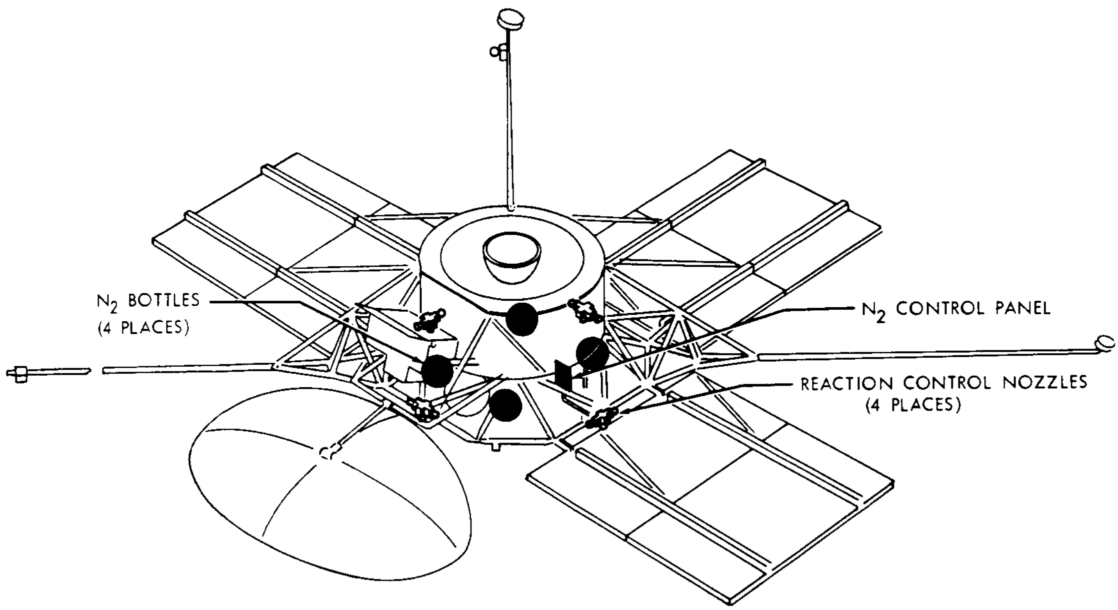


Figure 18: Voyager Flight Spacecraft — Reaction Control

simple, reliable components that are space-proven, or can be adequately qualified before the July 1966 design-freeze date. Every basic component is supported by a redundant unit (of dissimilar design where practicable) so that a single basic component failure will not prevent achievement of mission objectives. Modular design and simplified interface will minimize the problem of system integration, system checkout, simulation, test, spares, and module replacement. Pertinent characteristics of the attitude reference and autopilot subsystem are listed in Table 4.

Replaceable modules of the subsystem will be the prealigned attitude reference module, the autopilot module, and three remote coarse Sun-sensor assemblies.

Reaction Control

The reaction-control subsystem (Figure 18) uses the cold-gas, mass-expulsion concept of reaction control. Control moments are produced by expulsion of nitrogen from 0.25-pound thrusters, located on the periphery of the spacecraft body. The thrusters receive commands from the autopilot and are arranged in two completely redundant sets. Selection of one or both of the thruster sets is controlled by the central computer and sequencer (CC&S) by means of solenoid latching values. A total of 60 pounds of sterilized nitrogen, of which 15 are reserved for use by the propulsion subsystem as pressurant, is stored at 3500 psia in four tanks. Regulators reduce this pressure to 50 psia for use by the thrusters. Total subsystem weight is 212 pounds. It provides a total impulse of 3040 pound-seconds.

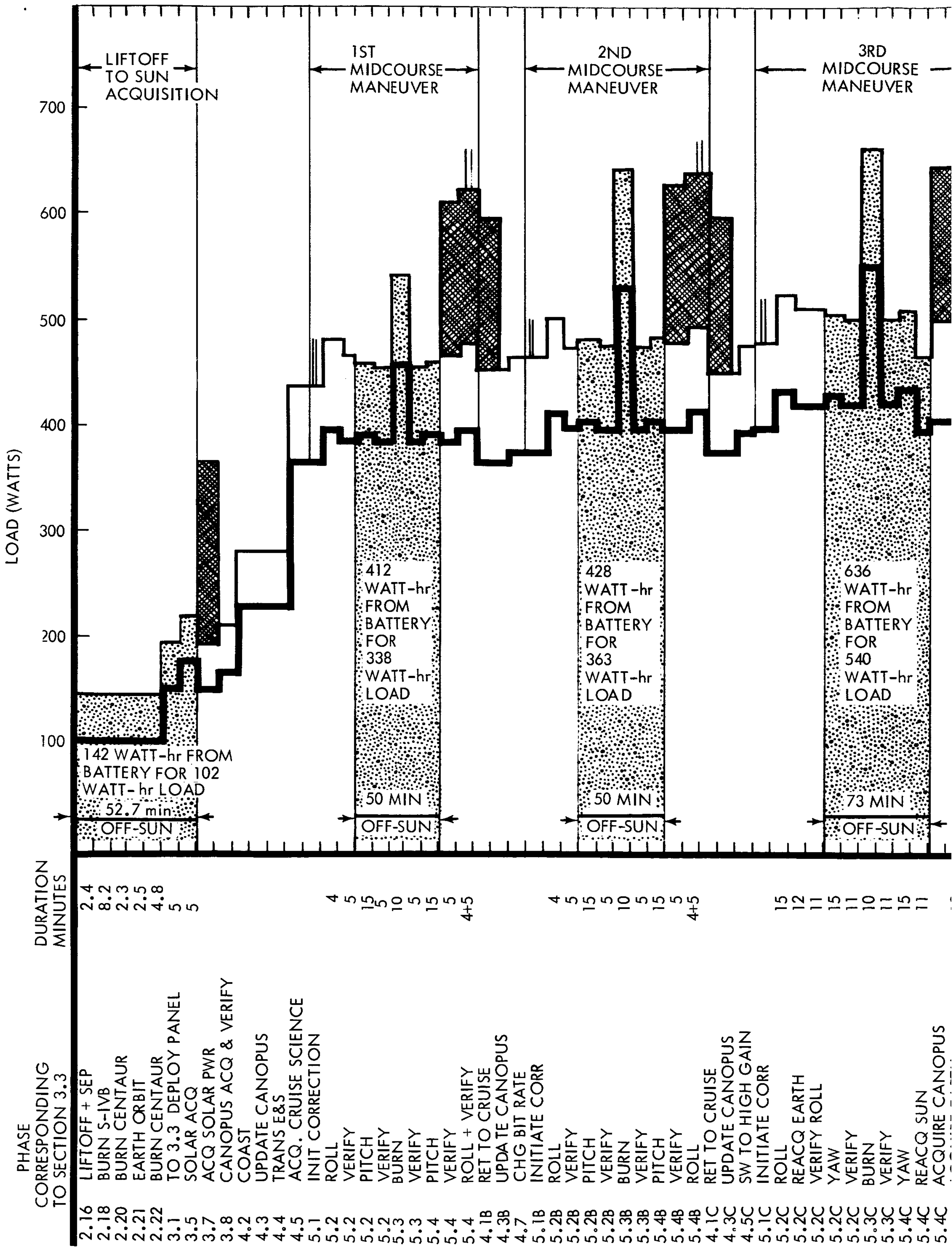
The reaction-control subsystem uses proven concepts and components throughout. Nitrogen has been used extensively in space as a control-system propellant and is clean, stable, and easy to handle. Thrusters, solenoid valves, regulators, and check valves are identical (or similar) to components used in Ranger, Mariner, Lunar Orbiter, and OGO. Tanks in the subsystem are made of 6Al-4V annealed titanium with a hazard factor of 2.2 (ultimate) for safety. All connections in the stainless-steel propellant lines are brazed for minimum leakage. Propellant loading is based on a safety factor of 2, applied to computed impulse requirements. Overall subsystem reliability is 0.9996. The reaction-control subsystem must be sterilized to avoid planetary contamination by thruster emissions. The design is compatible with the JPL-approved heat-soak sterilization technique.

Electrical Power

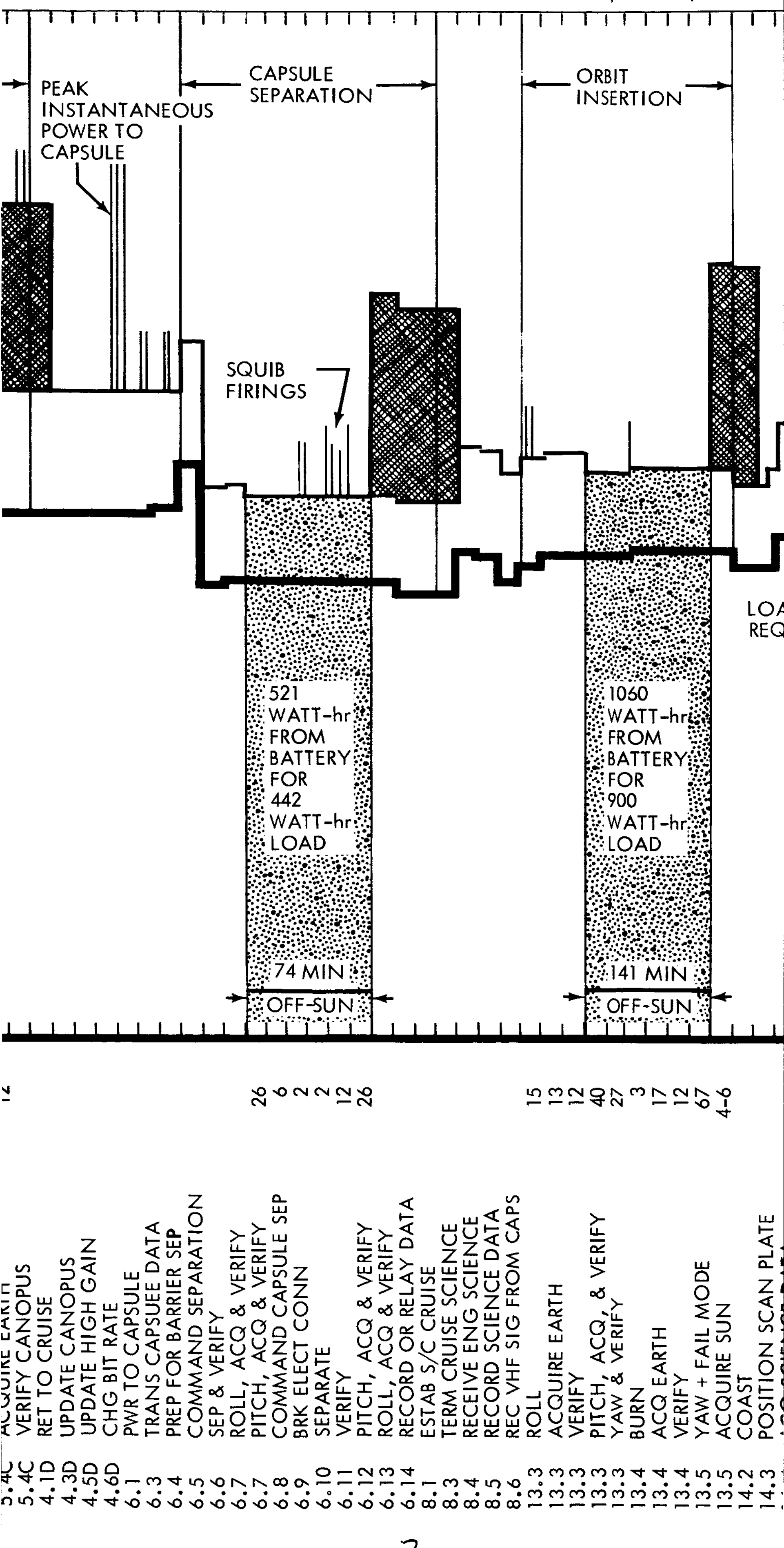
The power subsystem provides electrical energy from a solar array and from secondary storage batteries for operation of spacecraft subsystems during the various phases and maneuvers of the mission in accordance with the load profile shown in Figure 19.

Table 4: ATTITUDE REFERENCE AND AUTOPILOT CHARACTERISTICS SUMMARY

System	Reliability (Probability of Success)	Weight (pounds)	Electrical Power Dissipation and Sources					
			Power Input (watts)		Dissipated Power (watts)		Peak Power Duty	Primary Power Source
			Avg	Peak	Avg	Peak		
Attitude Reference and Autopilot Subsystem	0.9967	61.8						
Attitude Reference Module	0.9969	49.3	33.5	33.5	33.5	33.5	100%	+35 v.d.c 1∅ 2400
IRU	0.9993	22.4						
Canopus Tracker	0.9984	13.5						
Sun Sensor	0.9992	2.5						
Structure and Miscellaneous		10.9						
Autopilot Module	0.9998	11.0	12.0	79.0	7.5	15.0	10 min	+35 v.d.c.
Remote Sun Sensors	(included above)	1.5						



LIFTOFF TO SUN ACQUISITION
1ST MIDCOURSE MANEUVER
2ND MIDCOURSE MANEUVER
3RD MIDCOURSE MANEUVER
LOAD (WATTS)
700
600
500
400
300
200
100
142 WATT-hr FROM BATTERY FOR 102 WATT-hr LOAD
52.7 min
OFF-SUN
412 WATT-hr FROM BATTERY FOR 338 WATT-hr LOAD
50 MIN
OFF-SUN
428 WATT-hr FROM BATTERY FOR 363 WATT-hr LOAD
50 MIN
OFF-SUN
636 WATT-hr FROM BATTERY FOR 540 WATT-hr LOAD
73 MIN
OFF-SUN
DURATION MINUTES
PHASE CORRESPONDING TO SECTION 3.3
2.16 LIFTOFF + SEP 2.4
2.18 BURN S-IVB 8.2
2.20 BURN CENTAUR 2.3
2.21 EARTH ORBIT 2.5
2.22 BURN CENTAUR 4.8
3.1 TO 3.3 DEPLOY PANEL 5
3.5 SOLAR ACQ 5
3.7 ACQ SOLAR PWR
3.8 CANOPUS ACQ & VERIFY
4.2 COAST
4.3 UPDATE CANOPUS
4.4 TRANS E&S
4.5 ACQ. CRUISE SCIENCE
5.1 INIT CORRECTION
5.2 ROLL 4
5.2 VERIFY 5
5.2 PITCH 15
5.2 VERIFY 5
5.3 BURN 10
5.3 VERIFY 5
5.4 PITCH 15
5.4 VERIFY 5
5.4 ROLL + VERIFY 4+5
4.1B RET TO CRUISE
4.3B UPDATE CANOPUS
4.7 CHG BIT RATE
5.1B INITIATE CORR
5.2B ROLL 4
5.2B VERIFY 5
5.2B PITCH 15
5.2B VERIFY 5
5.3B BURN 10
5.3B VERIFY 5
5.4B PITCH 15
5.4B VERIFY 5
5.4B ROLL 4+5
4.1C RET TO CRUISE
4.3C UPDATE CANOPUS
4.5C SW TO HIGH GAIN
5.1C INITIATE CORR
5.2C ROLL 15
5.2C REACQ EARTH 12
5.2C VERIFY ROLL 11
5.2C YAW 15
5.2C VERIFY 11
5.3C BURN 10
5.3C VERIFY 11
5.4C YAW 15
5.4C REACQ SUN 11
5.4C ACQUIRE CANOPUS


PEAK INSTANTANEOUS POWER TO CAPSULE
CAPSULE SEPARATION
ORBIT INSERTION
SQUIB FIRINGS
521 WATT-hr FROM BATTERY FOR 442 WATT-hr LOAD
74 MIN
OFF-SUN
1060 WATT-hr FROM BATTERY FOR 900 WATT-hr LOAD
141 MIN
OFF-SUN
26
6
2
2
12
26
15
13
12
40
27
3
17
12
67
4-6
5.4C VERIFY CANOPUS
4.1D RET TO CRUISE
4.3D UPDATE CANOPUS
4.5D UPDATE HIGH GAIN
4.6D CHG BIT RATE
6.1 PWR TO CAPSULE
6.3 TRANS CAPSUEE DATA
6.4 PREP FOR BARRIER SEP
6.5 COMMAND SEPARATION
6.6 SEP & VERIFY
6.7 ROLL, ACQ & VERIFY
6.7 PITCH, ACQ & VERIFY
6.8 COMMAND CAPSULE SEP
6.9 BRK ELECT CONN
6.10 SEPARATE
6.11 VERIFY
6.12 PITCH, ACQ & VERIFY
6.13 ROLL, ACQ & VERIFY
6.14 RECORD OR RELAY DATA
8.1 ESTAB S/C CRUISE
8.3 TERM CRUISE SCIENCE
8.4 RECEIVE ENG SCIENCE
8.5 RECORD SCIENCE DATA
8.6 REC VHF SIG FROM CAPS
13.3 ROLL
13.3 ACQUIRE EARTH
13.3 VERIFY
13.3 PITCH, ACQ, & VERIFY
13.3 YAW & VERIFY
13.4 BURN
13.4 ACQ EARTH
13.4 VERIFY
13.5 YAW + FAIL MODE
13.5 ACQUIRE SUN
14.2 COAST
14.3 POSITION SCAN PLATE

2

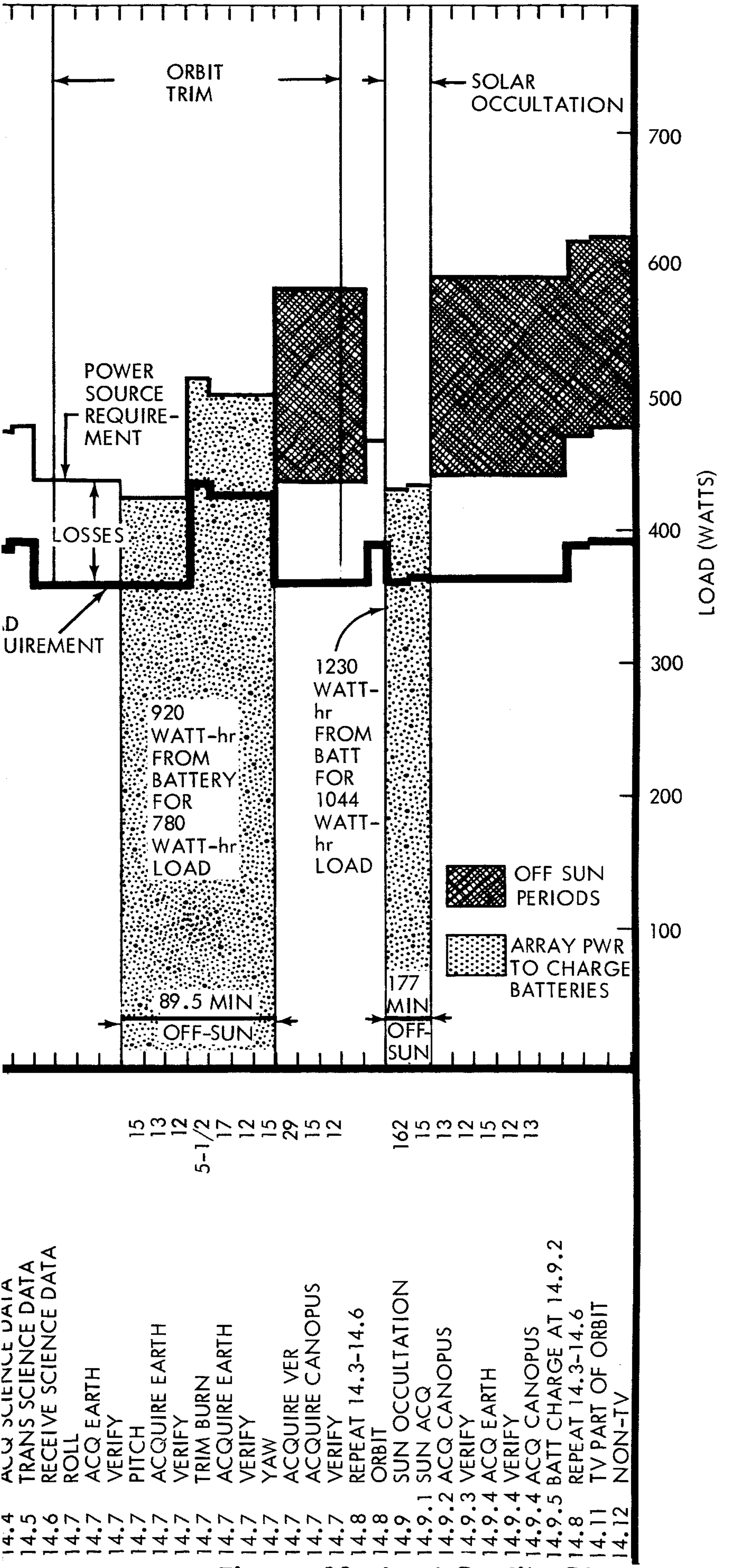


Figure 19: Load Profile Plus Source Profile 3

Investigation was made of electrical power requirements for the 1971 through 1977 Voyager missions. A solar/photovoltaic/battery system was verified as the optimum choice for the Voyager mission. The system uses n on p solar cells to provide 396 watts to the spacecraft loads from 236 square feet of solar panel area from three panels, each containing two structural sections. Wiring of the solar panels is arranged to minimize magnetic interference. A silver-cadmium battery, rated at 2460 watt-hours and arranged in three identical sections of 38 cells each is used. This conservative battery design will support up to 2.9 hours of predicted off-Sun operation (occultation during Mars orbit) with reserve capacity to accommodate unscheduled extensions beyond that. Battery size and circuit operation have been chosen so that the mission can be successfully completed if any one battery fails. Basic power regulation is accomplished by redundant series switching regulators within the electrical power system, with supplemental power conditioning being accomplished within each using subsystem. Power control and conditioning equipment, within the electrical power subsystem, provides for switching of solar array and batteries, automatic operation of battery charging, regulation of raw d.c. power, and 2400-cps power for operation of the Science Payload.

Equipment and logic are incorporated to enable sensing and control under different conditions of Sun-pointing and off-Sun operation and for electrical power subsystem equipment malfunctions with override control by Earth commands.

The major elements of the electrical power subsystem are shown in a simplified block diagram (Figure 20). These same major elements are shown in the isometric (Figure 21) as they relate to the spacecraft configuration. Total subsystem weight is 457 pounds. The predicted reliability is 0.9969.

The design of the solar panels for the power subsystem is based on presentday technology. However, a relative unit weight reduction has been realized in the Voyager panels over the Mariner IV panels by elimination of the requirement to mount zener diodes on the panel and the use of a truss beam substrate support rather than a box beam substrate support.

An outstanding feature of the subsystem is that the wiring in the solar panels has been intertwined and routed to eliminate substantially the current field normally induced. The magnetic field produced by short-circuit current, under near-Earth conditions, has been held to less than 2 gamma at 10 feet by alternating the direction of current flow in adjacent submodule strings. With normal operating currents, the magnetic field 10 feet from the edge of the panel will be approximately 0.5 gamma.

Propulsion

The selected spacecraft propulsion subsystem (Figure 22) consists of a combined solid-fueled motor and liquid monopropellant subsystem. This propulsion module is the only design that satisfies all Voyager mission propulsion requirements from 1969 through 1977 within the specified 3500-pound weight limitation. (See Figure 23.) Spacecraft propulsion predicted reliability is 0.9968.

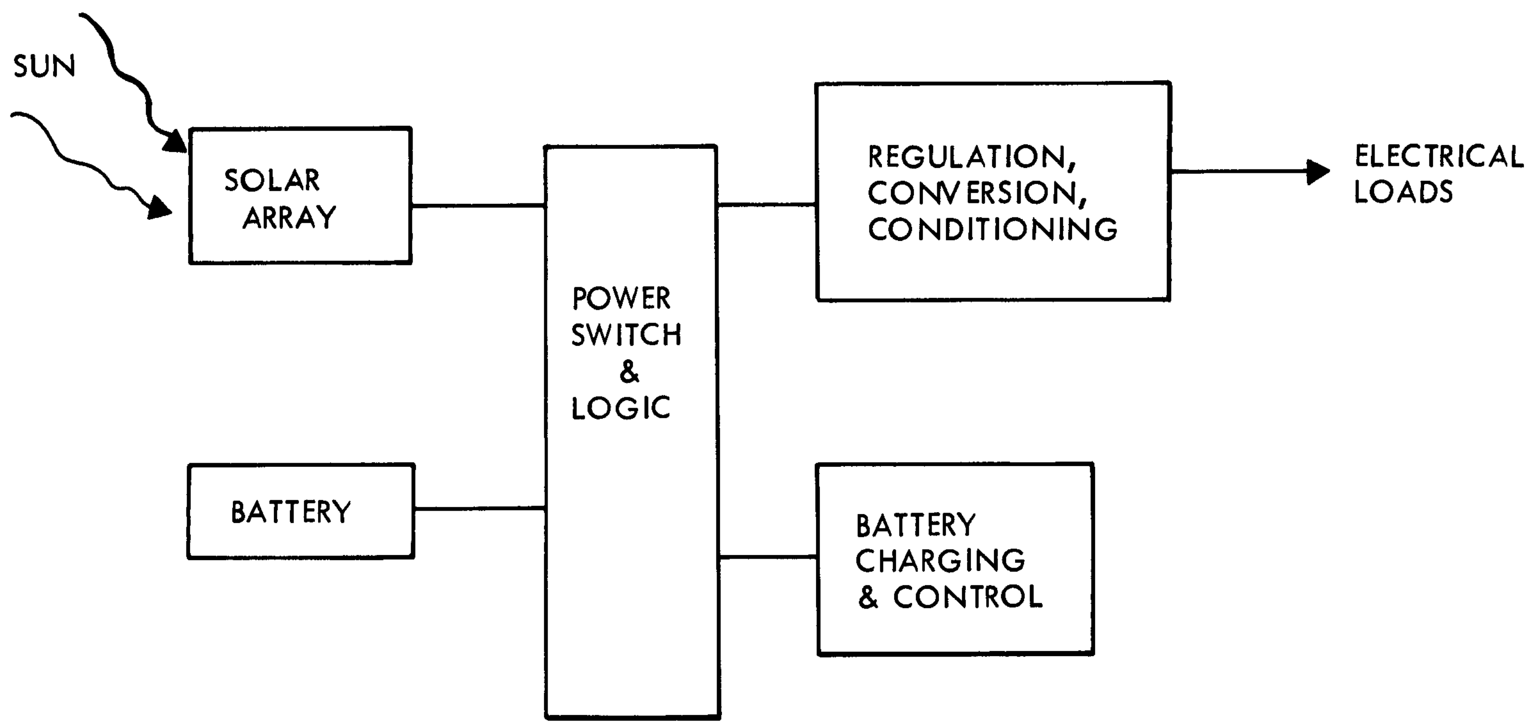


Figure 20: Electrical Power Subsystem Simplified Functional Diagram

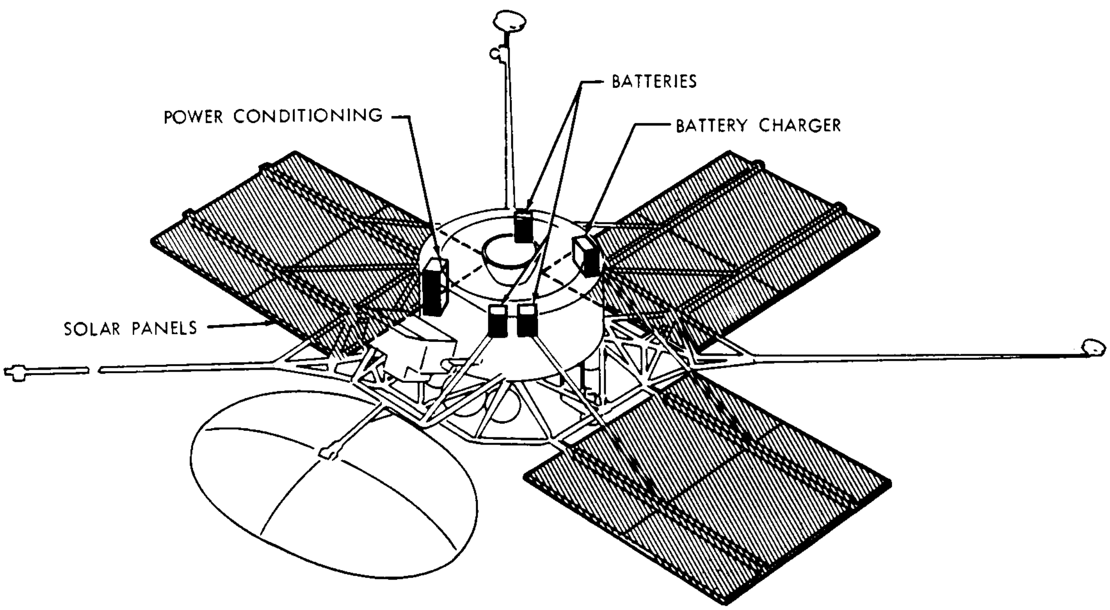


Figure 21: Voyager Flight Spacecraft — Electrical Power

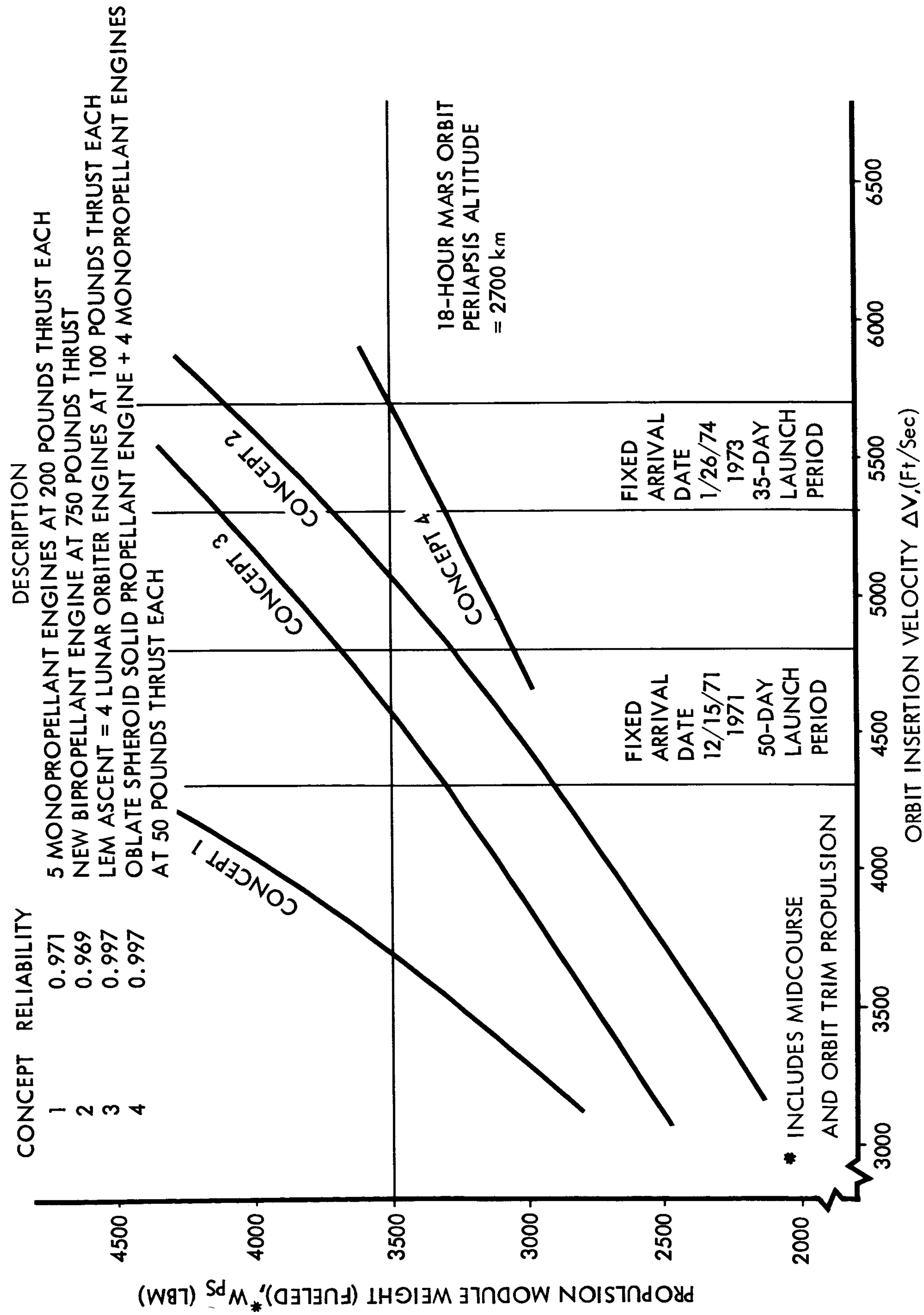


Figure 23: Spacecraft Propulsion Capability - orbit Insertion

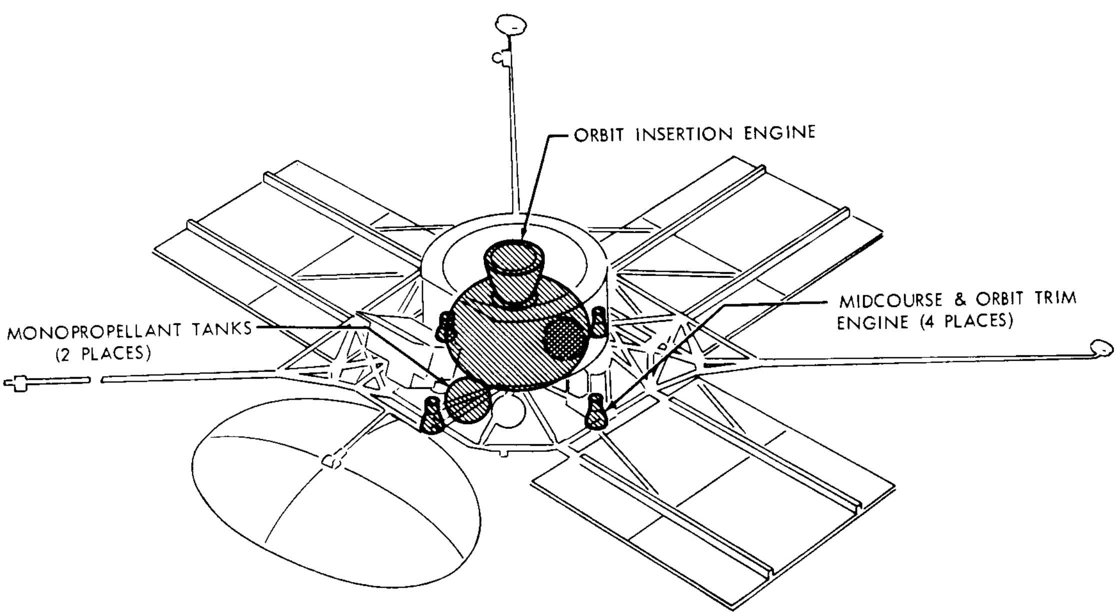


Figure 22: Voyager Flight Spacecraft — Propulsion

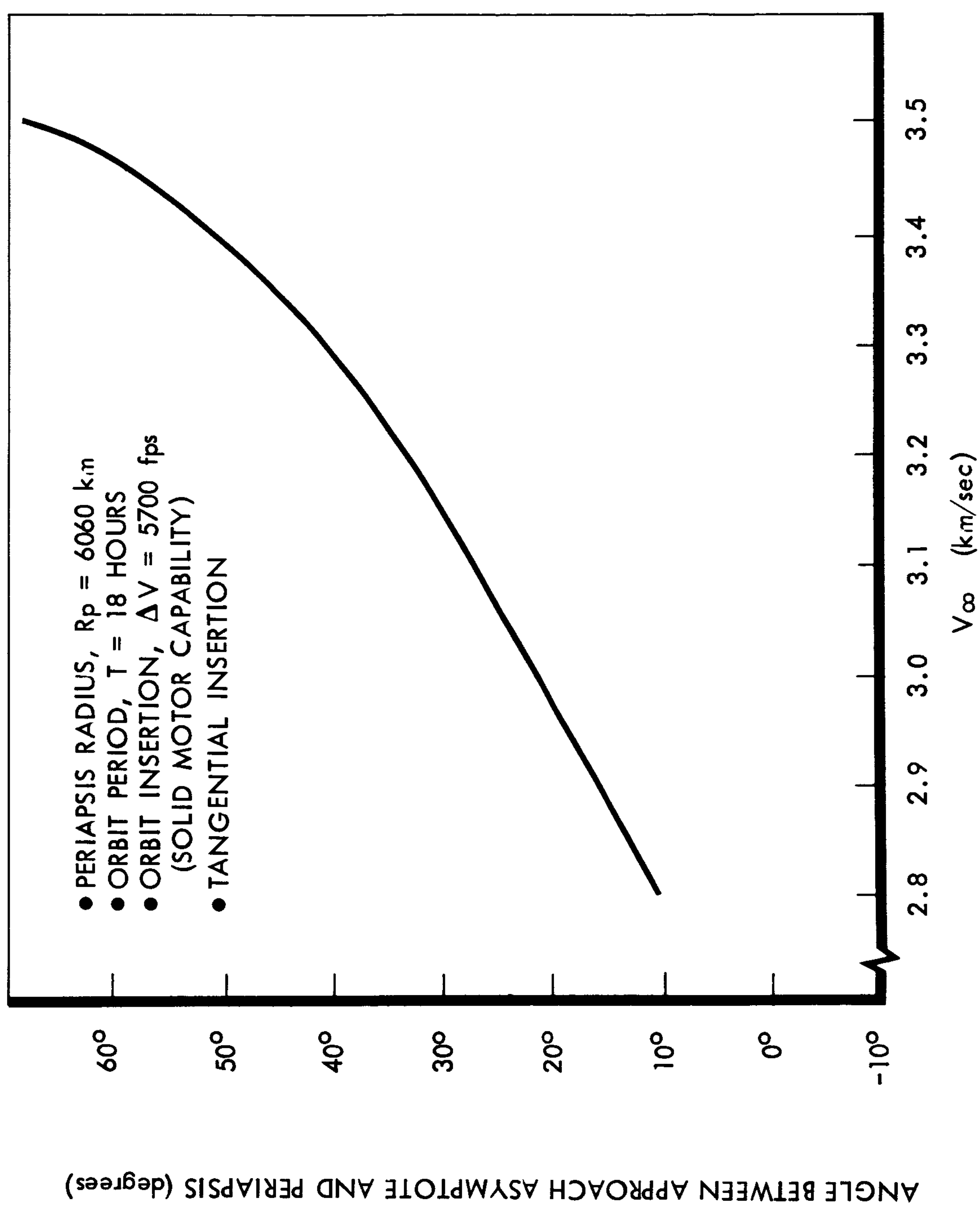


Figure 24: Variation of Periapsis Position

The orbit-insertion solid motor design relies on proven components and existing technology. The 65-pound oblate spheroid motor case is fabricated of glass filament and epoxy resin. Similar elliptical fiberglass domes are used on Polaris and Minuteman. A part of the weight contingency allows for switching to a titanium case, if required. The partially buried 103-pound nozzle is similar in concept and materials to that used on Minuteman. Motor-case geometry allows for a nozzle exit-area-to-throat ratio of 73 within module length restrictions. This results in a high specific impulse estimated at 300 lb(f)-sec/lb(m). It also results in low exhaust thermal radiation.

The propellant is aluminized polybutadiene, which was fully qualified on the operational Minuteman Wing VI. Propellant conocyl grain design has been successfully demonstrated on Skybolt. It provides for regressive burning that maintains a maximum acceleration during motor burn of 2.2 g's. The average nominal thrust is 7988 pounds. Ignition is provided by an aft-mounted, controlled-pressure Alclo-iron igniter, which has been successfully used in the Polaris missile. The motor case can accommodate 2838 pounds of propellant. It is loaded with only 2306 pounds of propellant to provide the required 5700 foot-per-second velocity increment within the 3500-pound weight constraint. Motor thrust termination is by normal depletion to maximize reliability, minimize dynamic and thermal interaction with the spacecraft, and keep insertion velocity 3σ tolerances to less than ± 20 feet per second.

The fixed total impulse of the motor can accommodate variable Mars-arrival hyperbolic excess speeds through an "off-periapsis" insertion maneuver, as shown in Figure 24. The resultant shift in Mars-bound orbit periapsis position is small, and frequently results in an improved position.

Solid motor pitch-and-yaw thrust-vector control is provided by a 108-pound secondary injection system using 61 pounds of Freon 114B2 as injectant, and 3 pounds of unregulated nitrogen gas from the reaction-control-subsystem supply as pressurant. This Freon secondary injection system is similar to those used on Minuteman, Polaris, HiBEX, and Sprint.

The midcourse and orbit trim liquid monopropellant subsystem makes maximum use of JPL's Mariner and Ranger technology and experience. The 50-pound thrust level of each of the four regulated-pressure-fed, radiation-cooled, hydrazine engines is identical to that of the Mariner and Ranger engines. Similar engines, which use Shell 405 spontaneous decomposition catalyst, are currently being designed and tested under NASA Contract NAS7-372. The Shell 405 catalyst is utilized to increase reliability and provide multiple-restart capability.

Midcourse and orbit trim engines are fired in pairs for redundancy. Their predicted minimum velocity increment capability of 0.013 m/sec ± 10 percent is almost an order of magnitude lower than the desired minimum increment. Thrust-vector control, as on Mariner, is accomplished by jet vanes (four per engine). A total of 395 pounds of hydrazine is stored in two spherical tanks containing the Mariner-proven butyl bladders for positive expulsion. Bladder

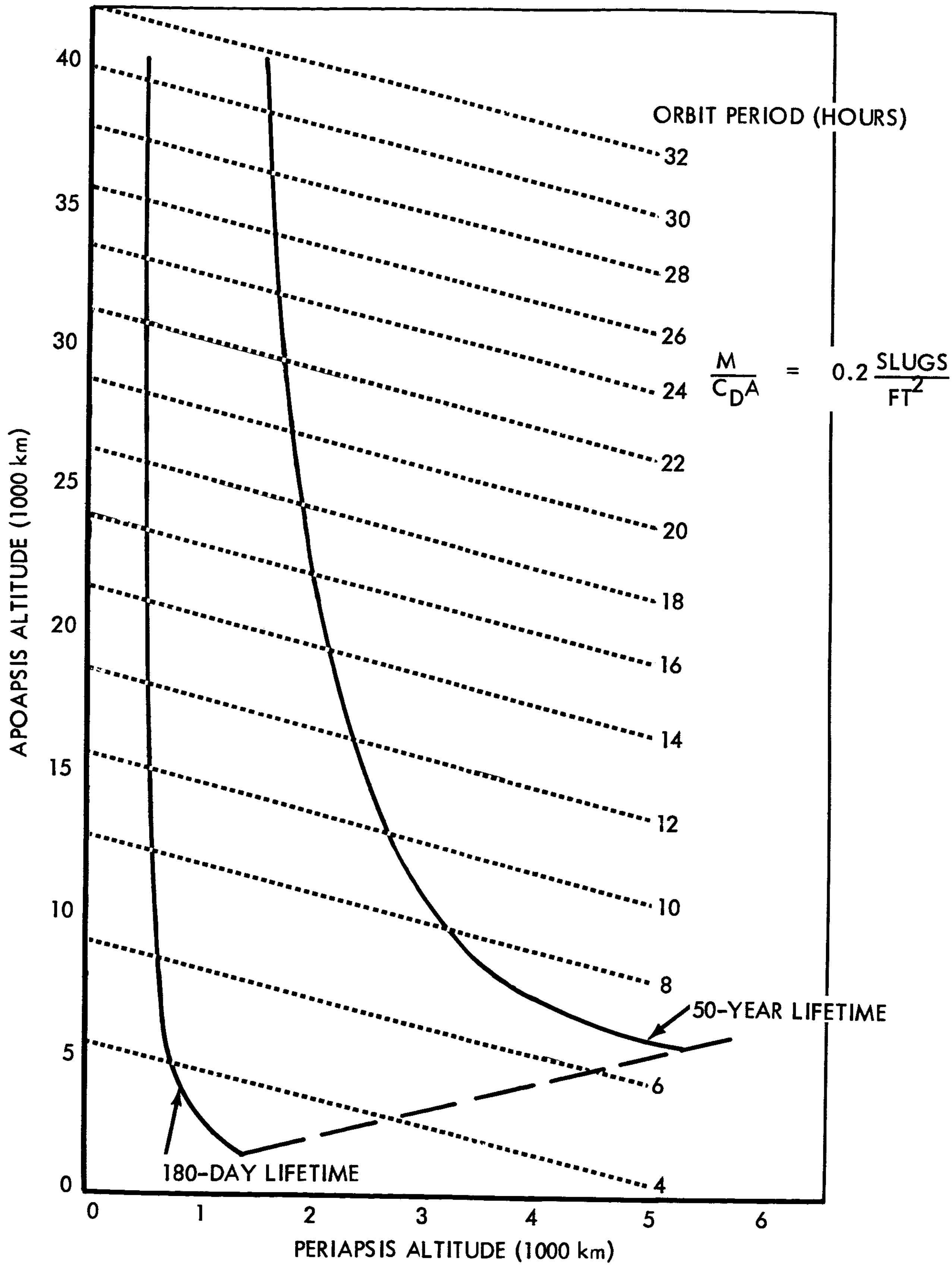


Figure 25: Typical Orbit Lifetimes

pressurization is furnished by 15 pounds of regulated nitrogen gas, drawn from the reaction-control-subsystem gas supply. Both pressurant and propellant are positively isolated after each firing to maximize reliability and minimize leakage.

The propulsion subsystem must be sterilized to prevent planetary contamination by exhaust ejecta. Sufficient development work has been accomplished to date on sterilization of solid propellant motors, hydrazine engines, and attendant subsystem components to consider them compatible with the JPL-approved heat-soak sterilization technique.

MISSION VERSATILITY

The capability of the preferred spacecraft design is such that a number of trajectories and orbits for the 1971 mission can be performed. In addition, the spacecraft capability affords considerable versatility in performing missions in the 1973-through-1977 opportunities as well as for the 1969 opportunity for the test flight.

The spacecraft can enter biologically safe orbits with periods as low as 18 hours from approach velocities (V_∞) at Mars, as high as 3.5 km/sec or with periods less than 9 hours from approach velocities as high as 3.0 km/sec. The 18-hour example provides coverage of four different swaths of Mars surface in the first 3 days after encounter. For the 3.5 km/sec approach velocity, encounter can occur when the annual Mars wave of darkening has its maximum contrast. At these early arrival dates, orbital periods greater than 18 hours can also be selected, as indicated in Figure 25. Alternatively, in the interest of obtaining more photographic data (at slightly lower quality), lower orbit periods can be achieved for later arrival dates. For example, the orbits at periods less than 9 hours can be established at arrival dates in the medium contrast time of the wave of darkening where V_∞ = 3.0 km/sec. Such lower orbits must have slightly higher periapsis altitudes, but they repeat their passage more often, taking and transmitting more photographic data during the orbiting phase of the mission.

In 1973 missions, the Type I transit trajectories typically have a short launch opportunity. The designed ability to accommodate Mars approach velocities as high as 3.5 km/sec allows a 37-day launch opportunity as compared to the 26-day opportunity of nearly mass-optimized trajectory sets.

Although present mission plans do not include it, the option exists of performing a similar orbital mission in 1975 over a relatively wide range of arrival dates (on the order of 100 days), or in 1977, if Type II transfers to Mars are used these years.

In 1971, orbits are available that have no occultation of Canopus or the Sun for the first 60 days in orbit. The periapsis positions are at southern latitudes and at illumination angles that favor the black-and-white TV experiment. Some adjustment of periapsis position is available at insertion by off-periapsis orbit

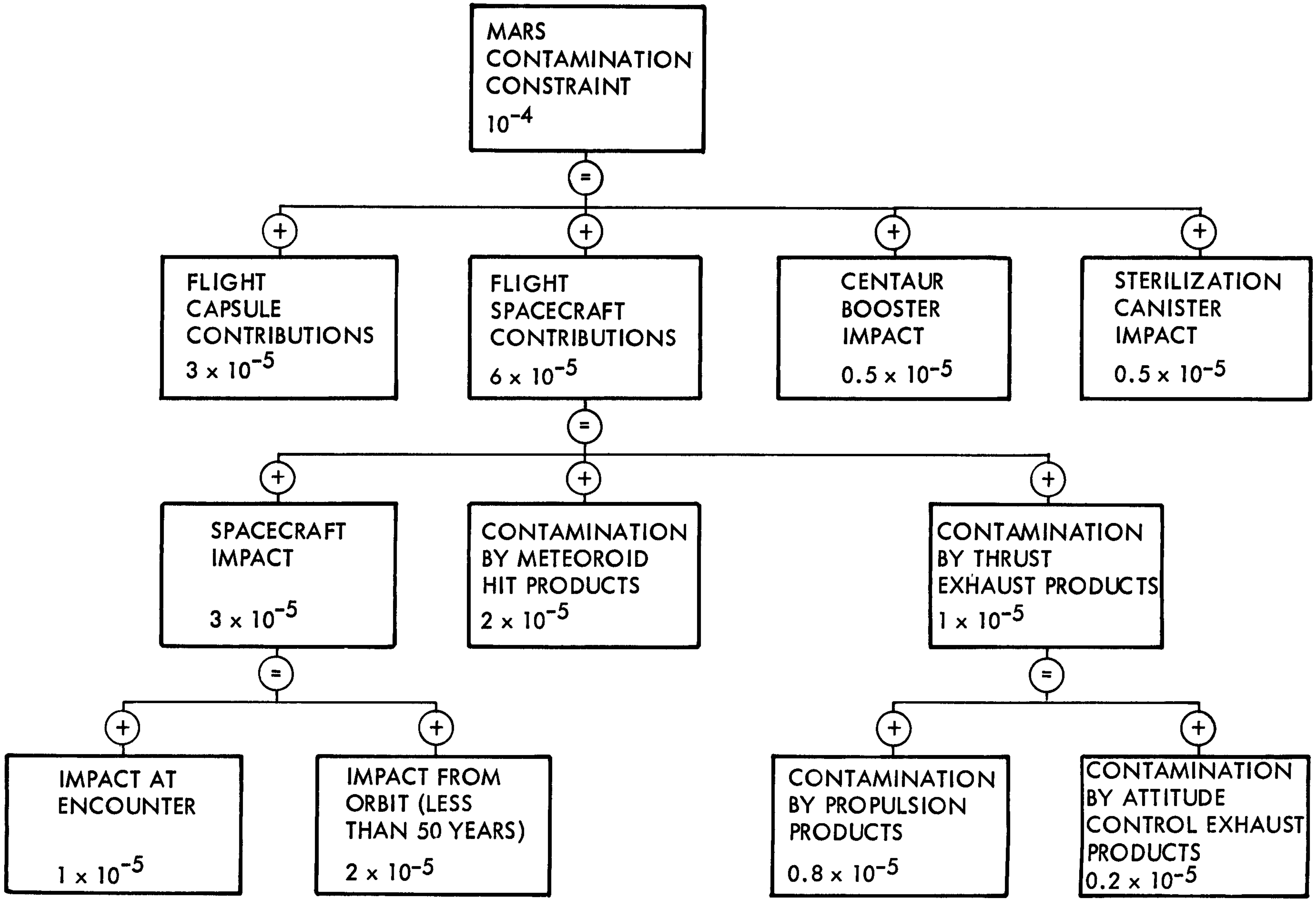


Figure 26: Mars Contamination Probability Apportionments

insertion. Additional impulse reserve for such an adjustment is obtained by choosing slightly later arrival dates with the present design.

The spacecraft is designed with a solid-propellant orbit-insertion engine that achieves a ΔV of 5700 feet per second within the 3500-pound weight restriction specified for the 1971 mission. However, the engine case has been designed at a very small weight penalty (approximately 20 pounds) to allow growth to a ΔV of 6550 feet per second if the 3500-pound weight restriction can be relaxed for other mission opportunities. This additional ΔV would provide even more flexibility in orbit size, periapsis placement, and arrival date.

PLANETARY QUARANTINE

Requirements and techniques for complying with the planetary quarantine constraint were generated and developed in conjunction with the spacecraft preliminary design during the Phase IA effort. The preferred design reflects the results of these studies.

The requirements were defined by an analysis performed to identify the probable sources of Mars contamination by the Planetary Vehicle, which resulted in an apportionment of the overall planetary quarantine probability of 1×10^{-4} to each of the possible contributing events or functions:

- Centaur booster impact;
- Capsule canister impact;
- Flight Capsule contributions;
- Flight Spacecraft accidental impact;
- Propulsion system exhaust products;
- Spacecraft meteoroid impact ejecta.

Allocated probability factors represented parameters to which the spacecraft flight sequence and subsystem designs were constrained. The individual probability apportionments are shown in Figure 26.

The probability allocations for accidental impact of the Centaur booster case, capsule canister, and Flight Spacecraft at encounter are met by biasing the aiming point. The selected range of orbits for the Flight Spacecraft is such that the probability of impact from orbit decay in less than 50 years is less than the allocated probability.

The requirements relating to thrust exhaust products and meteoritic spalling were extensively analyzed. These requirements cannot be met by trajectory alteration because an orbit that adequately precludes contamination from these sources must remain so far from Mars as to be relatively useless for data purposes. Mechanical methods also fail, as containment of exhaust products is impractical and meteorites are unavoidable.

On the basis of the results of these analyses and on consideration of the ramification of sterilization treatment techniques, it was considered prudent to sterilize all the propulsion and attitude control systems as the preferred concept. Refinement of the analyses and further consideration of the operational problems appear necessary before specific constraints can be imposed on spacecraft surfaces and protuberances subject to meteoroid impact.

System constraints are satisfied by trajectory control and treatment of portions of the spacecraft to reduce microbial load. Subsystem constraints are met by providing sterilization barriers as required, by selecting compatible materials to withstand the thermal treatment, and by designing high reliability into mechanisms and subsystem components, through careful selection of space-proven parts and materials and through redundancy.

1969 TEST FLIGHT

The Boeing Company recommends that the 1969 test flight be included in the Voyager program. The 1969 test flight, with either of the two recommended test spacecraft described below, can be phased with the 1971 mission schedule so that test data are provided in time for corrective action to be taken in the 1971 spacecraft. The test flight is a phase of a total test program, progressing from component testing to flight testing, with each phase contributing to the success of the 1971 mission. Its particular virtue is that it is an opportunity to bring all system elements together for the first time in the actual environment. In addition to being a test of the spacecraft subsystems, singly and together, the 1969 test flight will test operations procedures, personnel proficiency, and the operational support equipment subsystems and their compatibility with each other and the spacecraft. Defining and solving potential problems in these test areas in 1969 will enhance the probability of mission success in 1971.

Considerations of the 1969 test flight as outlined in Volume D include a number of options relative to launch vehicle and flight mission combinations:

Launch Vehicle	Mission
Atlas/Centaur	Flyby Heliocentric (simulated flyby) Earth Orbital
S-IB/Centaur	Mars Orbital Flyby Heliocentric (simulated flyby)

The Boeing spacecraft configuration is adaptable to the Atlas/Centaur launch vehicle with minimum modifications (principally to the solar panels and high-gain antenna), thereby retaining a high degree of commonality to the 1971 configuration. In the case of the Saturn IB/Centaur, the test spacecraft identical to the 1971 configuration may be used. The decision as to launch vehicle selection can be delayed as late as February 1967 since the lead time required for the Saturn IB/Centaur is approximately 21 months. Considering this flexibility relative to decision timing together with the high degree of commonality of the testcraft in the case of either launch vehicle, it may be advisable to begin the design for use of the Atlas/Centaur and switch to the Saturn IB/Centaur when its availability is ensured.

Of the several options listed previously, the Boeing-recommended test spacecraft and flight missions are described below in order of preference.

- A test spacecraft that is a duplicate of the 1971 spacecraft, launched by a Saturn IB/Centaur and placed in Mars orbit after separating a simulated Flight Capsule into a trajectory away from Mars;
- A test spacecraft that is a minimum modification from the 1971 spacecraft, launched by an Atlas/Centaur and placed on a Mars flyby trajectory.

Although the flight profiles recommended for each of the alternative test spacecraft are the most desirable in each case, significant data can still be obtained if the corresponding target launch dates are not met. If the 1969 Saturn/Centaur test were unable to meet the launch dates required for a Mars orbit, it would still be possible to launch a Mars flyby trajectory. Failing that, a heliocentric orbit that simulates a Mars flyby could be attempted. If the 1969 Atlas/Centaur test were unable to launch in time for a Mars flyby, it could be placed on a simulated Mars flyby trajectory.

The upper atmosphere wind and gust velocities will be an important factor in the choice of launch vehicles for the 1969 test flight. The probability of a successful Atlas/Centaur launch during the March Mars flyby opportunity is as low as 2 percent. This indicates that an Atlas/Centaur-launched 1969 test flight will almost certainly be a simulated rather than actual Mars flyby.

The basic structural frame of the Boeing-preferred spacecraft will mate with the Atlas/Centaur; however, some modification to the appendages to meet shroud envelope constraints and some reduction in weight to meet payload limitations of the Atlas/Centaur are necessary. The primary modifications required are:

- Substitution of an 8-foot circular dish antenna instead of the 8-foot by 12-foot paraboloid and a different manner of folding for stowage;
- Use of three instead of six solar panels and a different method of storage;
- Use of two instead of three battery sections;
- Reduction in tank sizes for midcourse propulsion and attitude control; the number of tanks remains the same;
- Deletion of the solid-propellant orbit-insertion motor.

The Atlas/Centaur-launched 1969 test spacecraft is shown in Figure 27.

The use of the 1971 spacecraft, with simulated Flight Capsule, launched by the Saturn IB/Centaur is preferred because it completely tests all system elements and demonstrates capsule separation and spacecraft orbit insertion — critical Voyager 1971 mission events that do not have a background of previous experience. Further, it affords the opportunity, if desired, of obtaining additional data (over Mariner IV results) relative to the critical design environments of magnetically trapped radiation and meteoroid flux in the vicinity of Mars.

ADDITIONAL CONSIDERATIONS

During the development of the preliminary spacecraft design, a number of items that could enhance the 1971 Voyager mission were identified. Although these items have not been studied in detail, preliminary investigation indicates that further examination is warranted. Because of the potential enhancement offered by the following items, it is recommended that they be studied further during the forthcoming Phase IB effort.

1969 Test Flight Orbiter Use in 1971

Should an orbiting vehicle be used for the 1969 test flight, several interesting applications are possible in connection with the 1971 mission, provided the test vehicle is still operative. Applications that conceivably could enhance the 1971 mission appear in the areas of data management, navigation and orbit determination, and scientific investigations.

A transponder on the 1969 test vehicle would provide some improvement for the 1971 vehicle in Mars approach navigation uncertainties and orbit determination.

Scientific experiments involving two satellite spacecraft in Mars orbit is another possible use of the 1969 test vehicle. Potential investigations would include occultation in both the r.f. and visible spectrum, and dual-frequency radio and radar experiments. Unique equipment could be installed on the test vehicle, thus minimizing effects on the 1971 vehicle.

With two satellite vehicles in Mars orbit, it may be possible — with proper phasing — to maintain continuous communication with the 1971 lander. This feature, in conjunction with the real-time data-transmission capability of the Boeing-preferred spacecraft design, should enhance the probability of Flight Capsule mission success.

Another interesting possibility with two satellite vehicles is that continuous Earth coverage of engineering data from the 1971 spacecraft, even when it is occulted from Earth, may be attainable. This would afford the opportunity of detecting malfunctions while the 1971 spacecraft was traversing the "back side" of Mars, perhaps in time to effect corrective action via ground command relayed through the 1969 orbiting testcraft.

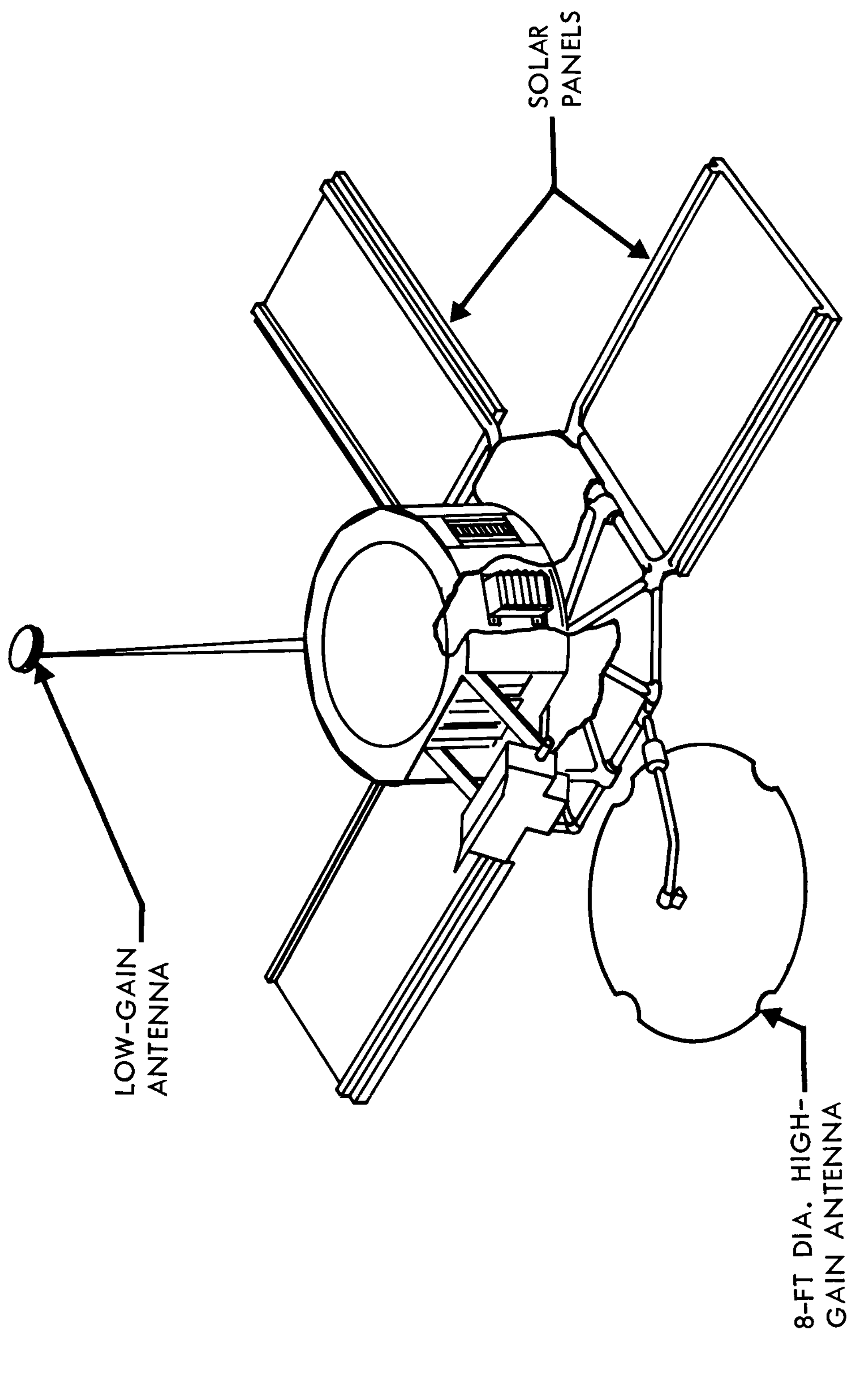


Figure 27: 1969 Test Spacecraft — Atlas/Centaur

All these possibilities offer some potential for enhancing the Voyager 1971 mission. Detailed analyses are required to evaluate the actual merit from the total systems standpoint.

In-Orbit Maneuvering

The propulsion module is sized to provide a 75-meter-per-second midcourse correction capability to the 7800-pound spacecraft, and a 100-meter-per-second orbit trim maneuver capability to the Mars orbiting spacecraft. Liquid-hydrazine propellant allocations for these maneuvers are 254 pounds for midcourse correction, 127 pounds for orbit trim, and 14 pounds for the propellant contingencies, making a total monopropellant load of 395 pounds.

Depending on launch dispersion errors and DSN capability, it is possible that only a portion of the midcourse propellant will be consumed prior to insertion. In this event, the unused midcourse propellant is available for in-orbit maneuvers performed subsequent to insertion.

If, for example, half of the midcourse propellant weight allocation was available for in-orbit usage, this would afford a ΔV augmentation of about 100 meters per second when applied to the in-orbit spacecraft mass. This, coupled with the orbit trim propellant allocation, would provide a total ΔV capability of 200 meters per second, which corresponds to approximately a 15-degree (at apoapsis) plane-change capability as opposed to a 7.5-degree capability if only the 100-meter-per-second orbit trim capability were available.

Various ways in which the in-orbit velocity increment capability can be used are:

- To change orbit plane to provide greater optical coverage of significant surface features, prevent occultation of either space reference bodies or Earth, and possibly to intercept the Martian moons, Phobos, and Diemos;
- To adjust the orbit periapsis altitude either lower to obtain better optical resolution or higher to obtain a longer orbit lifetime;
- To change the orbital period, if necessary, to increase communication time with Earth per orbit or obtain a desired ground track pattern;
- To change periapsis location (right ascension angle) to provide enhanced lighting conditions.

Further study of this particular item could assist in developing detailed in-orbit mission planning.

Use of Modified Lunar Orbiter Camera

It may be desirable to use the high-resolution camera developed for the NASA Lunar Orbiter to obtain high-quality photographs of Mars. The camera could be used in the 1969 test flight if the S-IB/Centaur is selected as the launch vehicle and an orbital mission is performed. Preliminary assessment has indicated that the 150-pound high-resolution camera could give ground coverage of an area of about 950 by 250 kilometers with a 60-meter resolution from 2700-kilometer altitude and would require approximately 20 hours per frame for transmission at a rate of 50,000 bits per second, assuming 6 bits per picture element.

To take advantage of the already developed Lunar Orbiter camera, it would be necessary to add an analog-to-digital converter to make the camera system's output compatible with the Voyager spacecraft telecommunication system. The addition of a digital-to-analog converter at the ground receiving station would also be required; however, the already developed Lunar Orbiter processing equipment could be used with the Voyager mission-dependent equipment for the remainder of the data-processing job. Some changes or additions in the Voyager Science Payload may be required, such as modification of the scan rate of the film scanner and the use of additional shielding to protect the film from nuclear radiation. Also, there may be some problem with extended storage of the film developer.

The possible gain in obtaining high-quality photographs of Mars through the use of already developed hardware from a previous program is attractive enough to warrant further investigation.

Improved Space Science from Spacecraft Sterilization

Since imaging experiments benefit from closer ranges, low-altitude orbits are desirable. If the entire spacecraft must be sterilized to meet the planetary quarantine constraint, the orbital-lifetime criterion becomes one of adequate mission time rather than the 50-year orbit-decay constraint. For the specified 6-month mission, orbits could be selected with periapses as low as approximately 600 kilometers. Considering the closeness to the planet and the uncertainty of the atmospheric density, it may be prudent to insert to an orbit with a higher periapsis (approximately 1100-kilometer altitude), and to adjust the periapsis downward after observing the orbit for a few days.

At the lower periapsis, somewhat less eccentric elliptical orbits are available using the 5700-fps orbit-insertion ΔV capability of the Boeing-preferred spacecraft design. (See Figure 25.)

The 600-kilometer periapsis altitude will facilitate detection of topographical features about one-fourth the size that can be detected from periapsis altitudes associated with biologically safe orbits (e.g., 2700 kilometers for the previously discussed example orbit having an 18-hour period). Format, field of view, image-motion compensation, data-accumulation rate, and transmission rate would require optimization under these constraints by the scientist-experimenter and the system integrator. Because of these intricate interrelations, detailed coordination is essential between JPL, the experimenter-scientist, equipment designer, and the spacecraft system contractor.

The lower-altitude orbits would provide, as a by-product, scientific data about the composition and properties of Mars atmosphere. With a sterilized spacecraft, the scientists would have the orbit altitude as a new variable to exploit in planning their experiments in all the Voyager flight opportunities.

QUALIFICATIONS

BOEING SYSTEMS INTEGRATION EXPERIENCE

The Boeing Company's role in the programs listed below has varied from prime weapon system contractor to associate contractor. In each case, the company has properly recognized the specific extent of its management responsibilities, and has developed the appropriate working relationships to fulfill its assigned role.

From previous system-integration experience acquired on major programs, Boeing understands the importance of thorough systems engineering. Applications of systems-engineering management techniques, in conjunction with appropriate management disciplines, will ensure that all elements of the Voyager spacecraft system are identified, that required trade-off studies are conducted, and that proper management control is exercised. Boeing has an active program to work closely with government agencies to meet the objectives of their management systems as determined for specific programs. It is recognized that the Voyager spacecraft system-integration task will represent an even higher degree of complexity and reliability than previously experienced. Experience as a system integrator, the close working relationship planned with team members, and, above all, the specific experience and technical skills of the people selected for the Boeing Voyager team qualify Boeing to perform this complex integration task.

Minuteman — Minuteman experience as the assembly and test and systems-integration contractor is particularly applicable to Voyager. Boeing was responsible for preparation of the master documents integrating the design, test, and interface control requirements activities of all associate contractors and government agencies; assembly of the master data-measurement list; and design of the PCM instrumentation system used for acquisition of performance data on associate-contractor-supplied motors, guidance and control system, ordnance, and structural systems.

The Boeing-designed Minuteman launch control system involved integration of complex electronic systems. The design and operation of the system-integration test facility at Seattle, in which all associate-contractor systems were installed and tested in an operational environment, entailed similar integration.

At Cape Kennedy, the assembly, test, and final checkout of all missile and launch electronics were performed. Data-reduction services were provided for all associate contractors and government agencies. Installation, checkout, and delivery of operational sites were accomplished in five states, maintaining configuration accountability and configuration control. In spite of major changes in operational requirements for launch-safety control, and a program acceleration of 1 year, all delivery dates have been met.

The Minuteman management control room in Seattle has been a model for control rooms established by Boeing for other programs. This management control room was established in 1961 and so favorably impressed the Air Force Ballistic Systems Division that BSD contracted with Boeing to install an almost identical control center at BSD Minuteman headquarters at San Bernardino, California. The installation was completed in 5 days. BSD frequently has used this control room for conducting joint BSD-San Bernardino/Boeing-Seattle reviews of the Minuteman program. Provisions are available for display of schedules, budgets, manpower trends, and performance.

X-20 Program — The X-20 program gave Boeing substantial experience in defining the detailed interfaces between spacecraft and booster. Under customer direction, the efforts of program associates and major vehicle subsystem contractors were integrated. Specifications were developed and subcontracts managed for the environmental control system, flight control system, auxiliary power unit, test data system (800 channels of PCM and FM/FM), abort-rocket system, and numerous other subsystems. Boeing was responsible for the design and procurement of the glider and ground support equipment, and for glider system-integration testing. In designing the vehicle, major state-of-the-art advances were achieved in many technical areas, including: thermal and boost loads analysis; fabrication and processing of refractory metals; design of very-high-temperature windows, antennas, and instrumentation; and sophisticated analysis of boost trajectories and re-entry dynamics. Characteristics of the vehicle's flight-control system were verified through use of a six-degree-of-freedom flight simulator.

Lunar Orbiter — In early 1964, Boeing won development responsibility for the NASA Lunar Orbiter. This responsibility includes design of the space vehicle and ground support equipment. Boeing is responsible for integrating subsystems into a complete space vehicle, with a reliability goal such that it can survive and perform a complex space mission of 1-year duration, and for integrating this space vehicle with the Atlas/Agena launch vehicle, launch facilities, and range facilities, including ETR and the deep-space-net tracking stations at Goldstone, Woomera, and Madrid. Responsibility encompasses mission planning, including orbital-mechanics calculations, and flight-test-data retrieval, reduction, correlation, and interpretation.

Saturn — NASA has contracted with Boeing for the Saturn S-IC space booster development and production and for the Saturn V system integration. Responsibility for the Saturn V interface management program includes preparation of all interface drawings for NASA. These interface drawings cover the physical, functional, procedural, environmental, and human engineering interfaces. On a company-sponsored basis, Boeing developed a computer model for simulating all operations and activities associated with assembly, test, and launch of a space vehicle and associated systems, including determination of the probability of successful launch. This model is being applied to the Saturn V system to obtain the optimized sequence of prelaunch events at Cape Kennedy.

The Saturn V management control center at Marshall Space Flight Center was designed and installed by Boeing. The center was operational on June 1, 1965, and is operated by Boeing for NASA. Complete program data is displayed on approximately 55 charts portraying program-level summary schedule information, stage-level schedule charts, technical performance information, and software display. The NASA Saturn V program manager uses this control center for staff meetings and for monthly program-level meetings. Closed-circuit television will be installed by October 1965 between MSFC, the Saturn test towers, Cape Kennedy, and Houston.

AUTONETICS EXPERIENCE

Autonetics is well qualified to solve design problems and to produce successfully the autopilot and attitude reference subsystem. Autonetics has completed a number of contracts in the space field. Recent contracted efforts include: ground support and spaceborne equipment development and fabrication for Apollo (NAA/S-IC prime); microelectronic systems for 461 (Lockheed prime); standardized space guidance system for Phase IA definition study (AS-SSC); automatic autonomous electrooptical orbital navigation investigation (AF-KT&D); and gyrocompass-in-orbit study (NASA-MSFC). In addition, Autonetics has component research contracts for space applications that include screening of transistors (JPL), microelectronics analog-to-digital converter (JPL), star gyro-torquing study (JPL), radiation effects on thin-film microcircuits (Fort Monmouth), and cadmium-sulfide photo technicalities (NASA-Langley).

PHILCO EXPERIENCE

The Philco Western Development Laboratories is extremely well qualified for designing and producing the telecommunication subsystem. Philco has completed the development of a sequence generator for JPL. The subsystem, implemented by integrated circuits, represents the majority of the spacecraft electronics required for the JPL interplanetary-ranging concept. The ranging system is used to determine unambiguous ranges up to 100 million miles with a range resolution of better than 1000 feet. This equipment constituted a major improvement in power consumption, size, and weight over the equivalent sequence generator used on Mariner C. Another class of spacecraft communication hardware fabricated at Philco is the antenna for a Mariner-series spacecraft. Philco has fabricated and tested flight models of the high-gain and omnidirectional antenna feeds and test probes, and associated cabling used on Mariner C, and has performed type-approval testing of the antenna systems. In addition, Philco is currently manufacturing the S-band test transmitter for JPL. This test transmitter is a sophisticated signal generator providing an accurately attenuated 2295-Mc output from -50 dbm to less than -150 dbm. In addition to the hardware described above, Philco has supplied over 400 space-vehicle communications subsystems and components for the Courier communications satellites and Air Force satellites. This equipment has had a remarkable record of success of proven reliability and has never been the cause of a failure jeopardizing the satellite mission objectives. The major types of subsystems provided are UHF traveling-wave-tube power amplifiers, S-band transponders, decoders, mixer filters, TIM generators, UHF and VHF transmitters, and UHF and VHF receivers.

ELECTRO-OPTICAL SYSTEMS EXPERIENCE

Electro-Optical Systems record in the production of electrical power in space has been outstanding and includes over 15 successes since 1962. In all but one instance (the first ion-engine ballistic flight), EOS power systems achieved their operational objective in space. Perfect performances were provided by the power systems for Rangers 6 and 7, and a similar feat has been demonstrated on the EOS-assembled solar panels on Mariner C. EOS contract experience considered applicable to Voyager includes: "Design and Development of Solar Concentrators," NAS7-10 (NASA); "Solar Thermionic Conversion System," 950109 (JPL); "Fabrication of Solar Cell Packages," L-26135 (JPL); "Mariner C Solar Panel and Power Subsystems," 950797 and 950022 (JPL); "Ranger 6-9 Program," 950565 (JPL); "Lightweight Solar Concentrators," NAS7-86 (NASA); and "Solar Panel Fabrication," AF33(616)-7346 (ASD).